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GLOBAL POSITIONING SYSTEM (GPS) FINAL REPORT

PART I

VOLUME C
Control Segment System Analysis Report

Contract F04701-73-C-0296

new - see AD 921 753

Submitted to:
DEPARTMENT OF THE AIR FORCE
HEADQUARTERS SPACE AND MISSILE SYSTEMS ORGANIZATION (AFSC)
P.O. Box 92960, Worldway Postal Center
Los Angeles, California 90009

TRW
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SAMSO TR 74-183

WDL Technical Report 5291
28 February 1974

GLOBAL POSITIONING SYSTEM (GPS)
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PART I - VOLUME C
CONTROL SEGMENT SYSTEM ANALYSIS REPORT

Contract F04701-73-C-0296

Prepared for

DEPARTMENT OF THE AIR FORCE
HEADQUARTERS SPACE AND MISSILE SYSTEMS ORGANIZATION (AFSC)
Los Angeles, California 90009

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PHILCO-FORD CORPORATION
Western Development Laboratories Division
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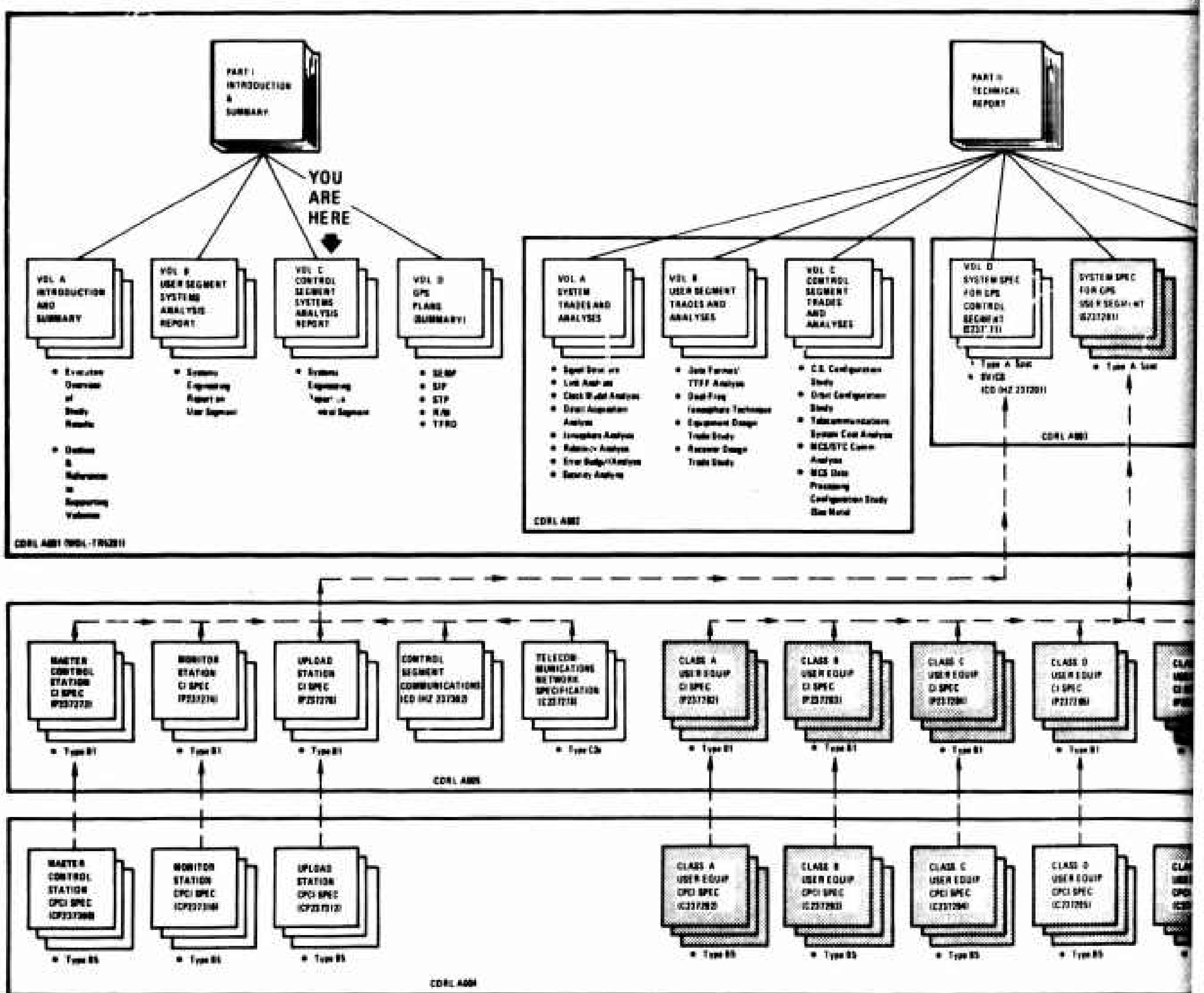
FOREWORD

This is Part I, Volume C, of the GPS Definition Study Final Report, submitted by Philco-Ford, in accordance with Sequence Number A001 of Exhibit A to Contract F04701-73-C-0296. The period of performance for the report submitted herein is from 23 June 1973 to 28 February 1974. The following figure identifies the structure of the Final Report and the relationship of this volume to the other volumes in this submittal.

WDL-TR5291
Part I
Volume C



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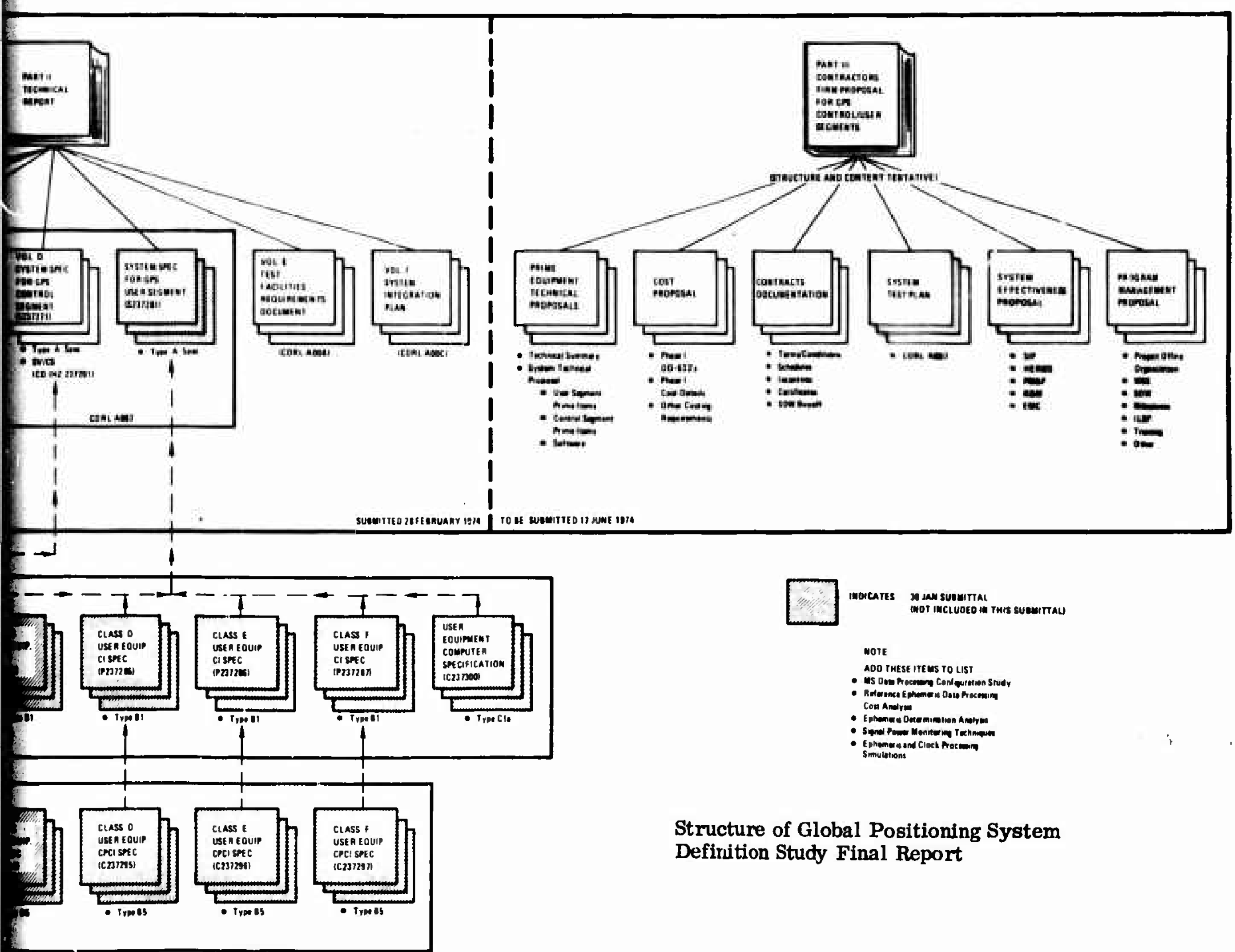

Structure of Global Positioning System Definition Study Final Report

ABSTRACT

PHILCO-FORD WDL-TR5291	UNCLASSIFIED
GLOBAL POSITIONING SYSTEM FINAL REPORT	
PART I, VOL. C	
SYSTEM ANALYSIS REPORT FOR THE CONTROL SEGMENT	F04701-73-C-0296
28 February 1974	283 Pages

This document provides a reference baseline description and performance analysis summary for the control segment of the Global Positioning System (GPS). Specifically included herein are: (1) a summary of GPS system requirements and their allocation to the control segment, (2) a functional description of the control segment hardware and software configurations, (3) operational setup and system calibration and testing concepts, and (4) analysis of various aspects of control segment performance structured to demonstrate that the proposed control segment configuration meets the allocated system requirements.

THIS UNCLASSIFIED ABSTRACT IS DESIGNED FOR RETENTION IN A STANDARD 3 BY-5 CARD-SIZE FILE, IF DESIRED. WHERE THE ABSTRACT COVERS MORE THAN ONE SIDE OF THE CARD, THE ENTIRE RECTANGLE MAY BE CUT OUT AND FOLDED AT THE DOTTED CENTER LINE. (IF THE ABSTRACT IS CLASSIFIED, HOWEVER, IT MUST NOT BE REMOVED FROM THE DOCUMENT IN WHICH IT IS INCLUDED.)

PHILCO Ford
Philco-Ford Corporation
Western Development Laboratories Division

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ILLUSTRATIONS

ILLUSTRATIONS (Continued)

ILLUSTRATIONS (Continued)

TABLES

GLOSSARY

A&C	alignment and calibration
ACU	automatic calling unit
ADL	automatic dial-up link
AFSCF	Air Force Satellite Control Facility
AGC	automatic gain control
AM	amplitude modulation
ANSI	American National Standards Institute
AUG	American wire gauge
AZ	azimuth
B/S	bits per second
BER	bit error rate
BITE	built-in test equipment
BPS	bits per second
BST	boresight tower
BTU	British thermal units
C/A	clear/acquisition
C/No	Carrier-to-Noise density ratio
CBS	refers to automatic DAA with voltage interface
CBT	refers to automatic DAA with contact closure interface
CI	configuration item
CITU	command interface and test unit
CPCI	computer program configuration item
CRT	cathode ray tube
CS	Control segment
CTC	cable termination cabinet
DAA	data access arrangement
dBi	gain, in dB, relative to isotropic
DCA	Defense Communication Agency
DDD	direct distance dialing
DL	dummy load
DVM	digital voltmeter
EIA	Electronic Industries Association
EIRP	effective isotropic radiated power
EL	elevation
ELM	Elmendorf Air Force Base
EMC	electromagnetic compatability
ETA	estimated time of arrival
FAA	Federal Aviation Agency
FET	field effect transistor
FFBD	functional flow block diagram
FM	frequency modulation
FSK	frequency shift keyed
GDOP	geometric dilution of precision
GPS	Global Positioning System
GPSTN	GPS Telecommunications Network

GLOSSARY

ICD	interface control drawing
IF	intermediate frequency
IF	intermediate frequency
IRIG	Inter Range Instrumentation Group
LO	local oscillator
L1,L2	L-band frequencies -- 1575 MHz, 1250 MHz (nominal)
MBAR	millibar
MCS	Master Control Station
MDL	manual dial-up link
MS	Monitor Station
MSG	message
MTBF	mean-time-between-failures
MTTR	mean-time-to-repair
NAG	Naval Astronautics Group
NAV	navigation
NBS	National Bureau of Standards
NFPA	National Fire Protection Association
NRZ	non-return-to-zero
NTS	Navigation technology segment
NWL	Naval Weapons Laboratory
P	protected
PA	power amplifier
PM	phase modulation
PPS	pulses per second
PRN	pseudorandom
PROM	programmable read-only memory
RCF	remote computing facility
RF	radio frequency
RH	relative humidity
ROM	read-only memory
RS232C	recommended standard number 232C (EIA)
SAR	system analysis report
SGLS	Space Ground Link Subsystem
STC	Satellite Test Center
SV	Space Vehicle
SVS	Space Vehicle
TN	telecommunications network
TRIB	transmission rate of information bits
TTL	transistor-transistor-logic
TTY	teletypewriter
UERE	user equivalent range error
US	Upload Station
VCO	voltage controlled oscillator
VLF	very low frequency
VSWR	voltage standing wave ratio
VTS	Vandenberg Tracking Station
WSMR	White Sands Missile Range

SECTION 1

INTRODUCTION

This system analysis report (SAR) has been developed as a product of the contract definition phase of the Global Positioning System (GPS) development program, to document the configuration and capabilities of the control segment of the GPS. This SAR combines a statement of control segment requirements with the results of a number of trade studies, system/subsystem design tasks and performance analyses addressing these requirements to produce a consolidated baseline and overview for the GPS ground segment.

1.1 REPORT STRUCTURE

The purpose of a SAR is to relate system (in this instance, the GPS control segment) requirements, configuration and performance (measured, if the system exists; derived from analyses for a proposed system) in a manner which validates the system design against the system requirements or which exposes shortcomings in the design. To achieve this purpose, the remainder of this report is structured into the following sections:

Section 2, Control Segment Requirements, which identifies the overall requirements to be satisfied by the GPS control segment. Further, in this section, segment requirements are allocated to the several elements of the control segment. In effect, this section addresses the question: What's expected of the GPS control segment?

Section 3, Control Segment Hardware and Software Description, which describes, using block diagrams with supporting narrative, the proposed equipment baseline configuration for the GPS control segment, and the software required to support the real-time operation and navigation functions of the GPS control segment. Section 3 treats the question: What is the GPS control segment?

Section 4, Control Segment Operations, which provides the manning requirements, function timelines and allocations, and an abbreviated "instruction manual" for the control segment and addresses the question: How is the GPS control segment to be configured and operated in support of the overall GPS mission?

Section 5, Control Segment Testing, which includes a test hierarchy (segment calibration and mission readiness tests down to equipment performance tests) that can serve as a guide for implementing a test

program to validate and maintain control segment performance. This section answers the question: How shouldt GPS control segment performance be measured and maintained?

Section 6, Ground Segment Performance, which documents the results of a number of trade-off and performance analyses undertaken to evaluate and/or optimize the ground segment hardware/software configuration. This section treats the question: What level of performance should be expected from the control segment? and thereby "closes the loop" by providing a comparison/validation of the segment's configuration against its performance requirements.

1.2 GPS OVERVIEW

The GPS is defined as, "... a space-based radio navigation system which, when combined with accurately positioned ground stations, will provide GPS equipped users the capability to precisely determine three-dimensional position, velocity, and reference time information, globally."[1] To provide this global navigation service the GPS assembles, and coordinates the operations of, four system segments, viz:

a. the satellite segment

b. the user segment

c. the control segment

d. the navigation technology segment

The role of the navigation technology segment (NTS) is to support the development of special items of hardware and software needed in the advanced phases of the GPS implementation. In this role the NTS is not involved in the day-to-day operations of the GPS. Therefore, insofar as this SAR deals primarily with the operational GPS, the NTS is given no further attention.

Before continuing with a description of the three operational GPS segments the implementation of the overall GPS is examined since it affects the configurations of the segments.

The GPS is to be implemented in three phases. Phase I is the concept validation phase during which the GPS concept and hardware/software designs will be validated, system costs will be defined and the military value of the GPS will be demonstrated. The phase II objectives will be to expand and optimize the GPS so that it can provide limited operational capability; ie, worldwide, continuous,

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[1] SS-GPS-101A: System Specification for the Global Positioning System.

two-dimensional navigation capability for a limited group of users. The phase III objectives shall e to expand to a worldwide three-dimensional capability. This SAR addresses the capabilities and configuration of the GPS control segment during phase I only.

Figure 1-1 provides an overview of the GPS showing the relationship of the system segments. Referring to the figure, the satellite segment consists of four satellites (this number grows to 24 in phase III) deployed as shown in Table 1-1. An artist's conception of the GPS space vehicles is provided in Figure 1-2.

TABLE 1-1

Satellite No.	1	2	3	4
Longitude of the Ascending Node (Deg)	195	195	75	75
Eccentric Anomaly (Deg)	41	81	64	124
Orbit Inclination (Deg)	63	63	63	63
Period (Hrs)	12	12	12	12

The particular orbit configuration shown in the table provides approximately two and one-half hours of test time (ie, the time during which all four satellites are simultaneously in view) per day at White Sands Missile RAnge, the phase I test area, while maintaining good satellite visibility from all the elements of the control segment.

The function of the spacecraft in the satellite segment is to receive RF signals, at S-band frequencies (specifically, 1750 MHz to 1850 MHz) transmitted from the control segment; process these signals to extract the navigation data (satellite ephemerides, satellite clock correction factors, etc); modulate the data, after reformatting, and an internally-generated pseudorandom range code onto two L-band carriers (L1, nominally 1575 MHz; and L2, nominally 1250 MHz) and broadcast the resulting spread spectrum navigation signals to the user and control segments. The user "navigates" with the signals (see Appendix A for a "thumbnail" description of the navigation procedure). The control segment uses the signals to 1) verify proper receipt, by the spacecraft, of the navigation data transmitted by the control segment to the satellite segment and 2) to "track" the spacecraft in order to determine their precise orbits. Two L-band signals are broadcast so that the user and control segments can correct for ionospheric refraction of the RF signals (given range measurements made at two widely separated carrier frequencies, and a simple model of the ionosphere, a correction for refraction can be readily computed).

The GPS user segment is defined as, "the total complement of equipment, software and procedures required for the reception and passive use of the GPS signals." Specifically, a single user equipment set consists of an omnidirectional receiving antenna

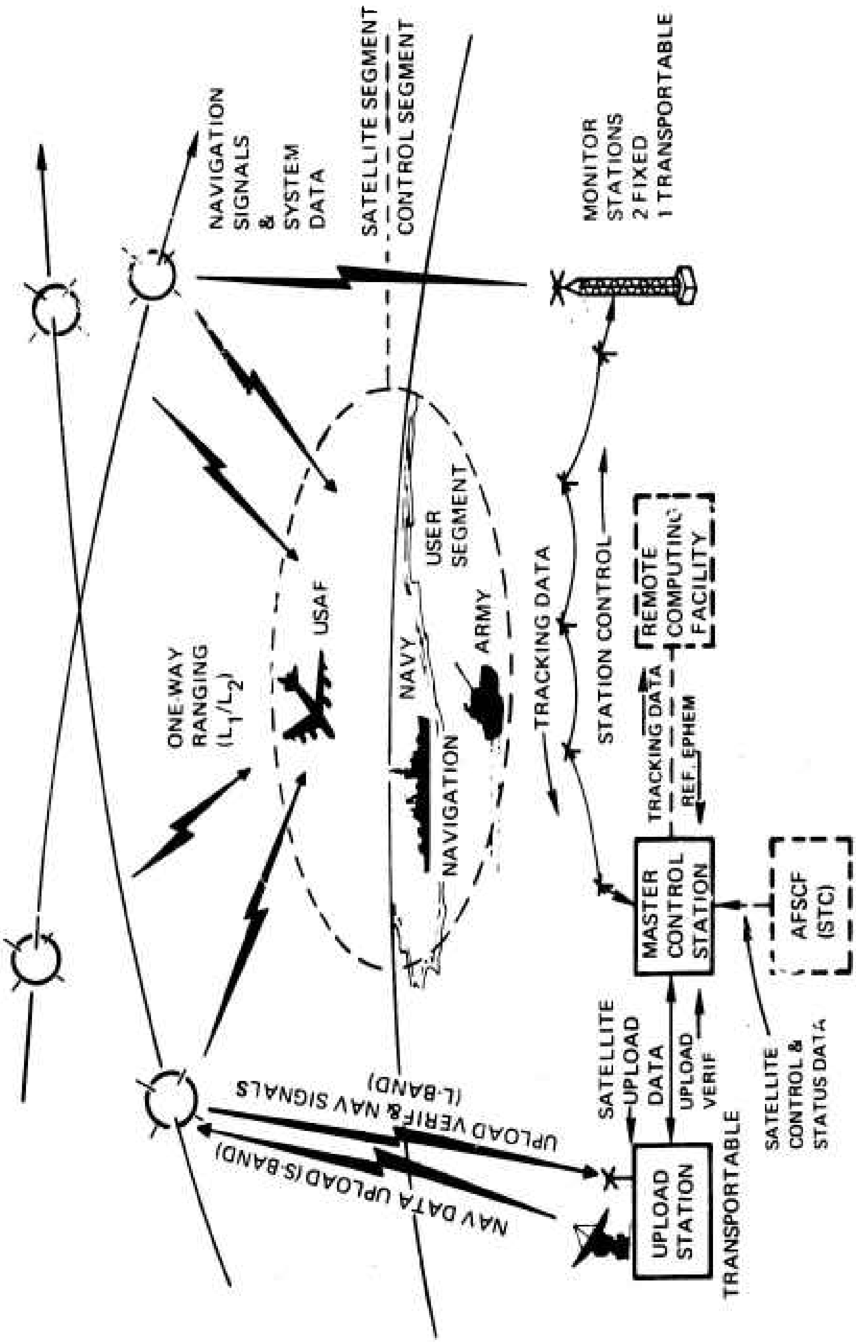


Figure 1-1 GPS Overview

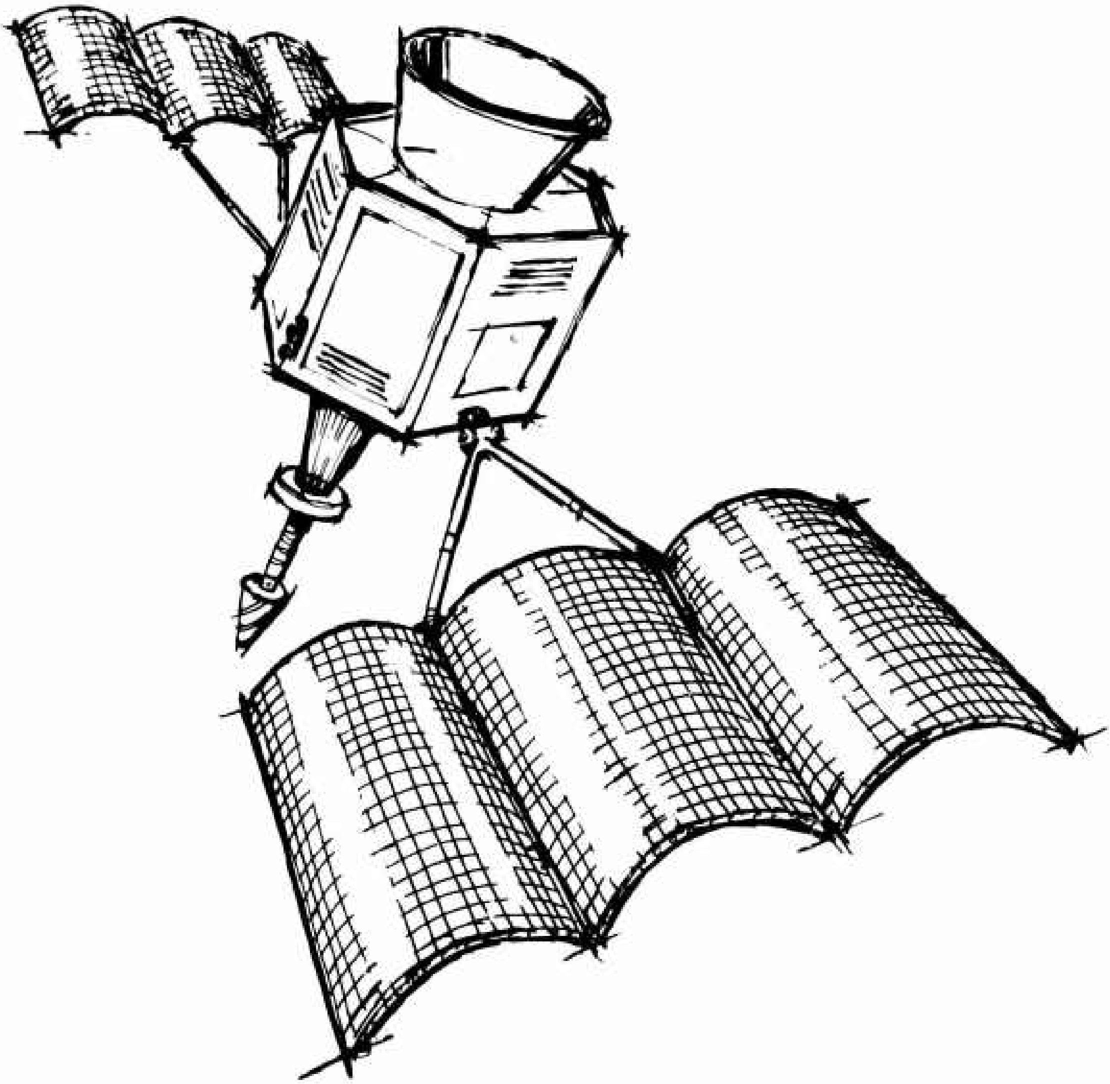


Figure 1-2 Artist's Concept of GPS Space Vehicle

(tailored to the service environment; ie, man-pack, airborne, etc), a receiver (designed to accept the navigation signals from each satellite and process them into digital data), and a computer (designed to accept data from the receiver and perform the data processing functions required for display of user position and velocity). Figure 1-3 shows a typical user set.

The GPS control segment consists of a master control station, three monitor stations, an upload station, and a remote computing facility. The role of the control segment is threefold: it generates the navigation signals and transmits them to the satellite segment, it utilizes the downlink navigation signals to accurately compute the satellites' ephemeris (because this ephemeris information becomes part of the navigation signal) and it monitors the downlink much like a user, to evaluate system performance. The ground segment does not, however, include the telemetry, tracking and command (TT&C) functions performed by the Air Force Satellite Control Facility (AFSCF) in support of satellite operations (eg, orbit maintenance, satellite "health"). Figure 1-4 shows the geographical arrangement of the CS elements and its supporting facilities.

1.3 CONTROL SEGMENT DEFINITION

Since the subject of this SAR is the GPS control segment, this segment is discussed below in somewhat more detail than the other two segments.

1.3.1 GPS Master Control Station

The GPS Master Control Station (MCS) is an aggregation of communications, timing and data processing equipment. The communications equipment serves to link the MCS with all the other elements of the control segment. The timing equipment, built around atomic time standards, provides the GPS time reference. And, the data processing equipment supports the orbit determination, space vehicle data base update generation and segment operations control functions of the MCS.

The MCS will be located within existing facilities at Vandenberg Air Force Base, California. Specifically, the MCS will be housed in building 22104, formerly an active AFSCF site. Figure 1-5 is an aerial view of the MCS.

1.3.2 GPS Monitor Stations

The GPS monitor stations (MS) will be located within currently existing Naval Astronautics Group (NAG) facilities at Wahiawa, Oahu, Hawaii and at Elmendorf Air Force Base, Alaska. In addition, one complete set of Monitor Station equipments will be provided for location at a designated location in the Southwestern United States.

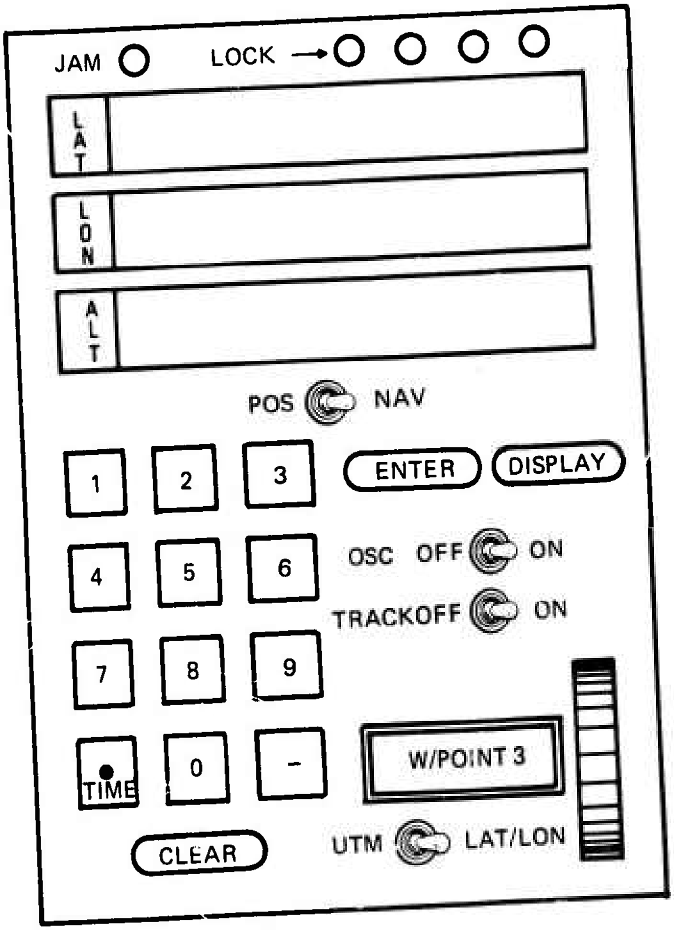


Figure 1-3 Typical User Set For Aircraft Deployment

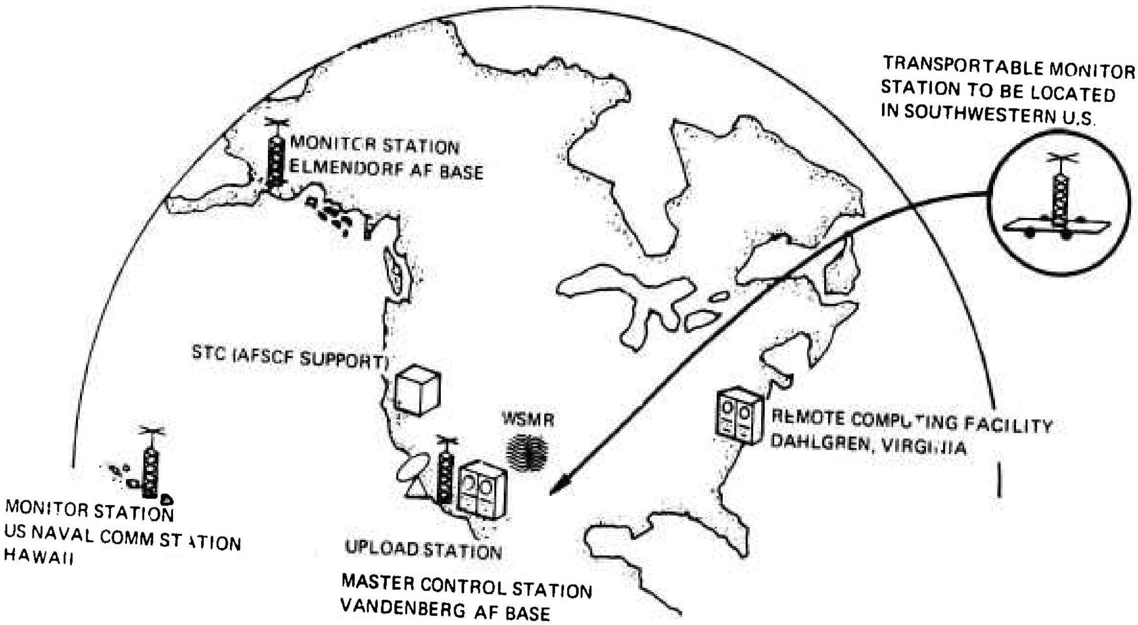


Figure 1-4 GPS Phase I Control Segment Configuration

Figure 1-5 Aerial View of Master Control Station

Physically, a MS is two racks of equipment plus a tower-mounted L-band antenna/preamplifier package and a meteorological monitoring package. The role of a MS is to receive the L1/L2 navigation signals from the GPS satellites and process the signals to extract pseudorange and pseudorange-rate data to be sent via land-line communication links to the MCS. In addition, the MS will assemble meteorological measurement data and forward this to the MCS along with the navigation data. The MSs will operate unattended and, therefore, will incorporate; in addition to their L-band receiving, data processing and communications equipment; automatic built-in test equipment to detect, and "advise" the MCS of station malfunctions.

1.3.3 GPS Upload Station

The GPS upload station (US) will be collocated with the MCS at Vandenberg Air Force Base, California. The US comprises the most diversified group of equipment of any of the control segment elements. To support its satellite upload function it incorporates communications equipment, linking it to the MCS; data processing equipment for upload message formatting and antenna pointing; a one kilowatt, S-band transmitter and a 15-foot diameter parabolic (directional) antenna (in the radome to the left in Figure 1-5). To verify that the satellite uploading has been satisfactorily accomplished the US includes L-band receiving equipment, duplicating that used at a MS, to receive an "upload accept/reject" signal from the satellite(s). When the receiving equipment is not being used for upload verification it serves to implement a fourth MS. In addition, the US collects meteorological data.

1.3.4 CS Telecommunications Network

The telecommunications element is an assemblage of wire-line modems and land-line communications circuits which serves to implement the long-distance, ground-based inter- and intra-segment interfaces.

1.3.5 Support Facilities

1.3.5.1 Remote Computing Facility

The GPS remote computing facility (RCF) will be the computational facility currently installed at the Naval Weapons Laboratory (NWL), Dahlgren, Virginia. The role of the RCF is to refine tracking data, received periodically (nominally, once per week) from the MCS, into precise reference ephemeris data for the GPS satellites. This reference data is then returned to the MCS to serve as the basis for its near-real-time orbit determination processing. (Appendix D provides, for reference, the NWL equipment configurations.)

1.3.5.2 AFSCF

The CS is supported by the Air Force Satellite Control Facility (AFSCF) and existing communications to provide emergency backup for uploading the navigational satellite.

SECTION 2

CONTROL SEGMENT REQUIREMENTS

The overall mission of the GPS is to, "...provide the capability to perform a wide range of position determining navigation functions including terminal and enroute nautical and aeronautical, all-weather, civilian and military navigation, midcourse guidance, weapon delivery, precise field artillery and shore bombardment, photomapping and phototargeting, on-board satellite position determination, relative time of arrival (TOA) targeting, precision rendezvous, blind landing, fleet ballistic missile inertial updating, unmanned reconnaissance and bombing, geodesy and survey, and time distribution..."[1] The role of the CS, in supporting the mission of the GPS, is to establish interfaces with the GPS space vehicles and with the AFSCF for the prime purpose of maintaining the space vehicles' navigation data bases. In addition to its operational role, the CS must contribute to the validation of the GPS concept by providing the means for validating CS hardware/software designs and for defining CS costs.

This section is an abridgement of the several specifications comprising the CS configuration baseline shown in Figure 2-1. It presents the general requirements to be met by the CS, in service to the GPS, and it documents the allocation of these requirements to hardware, software, and personnel within each of the CS elements.

2.1 CONTROL SEGMENT FUNCTIONAL REQUIREMENTS

The prime function of the CS is to provide periodic updating of the navigation parameters stored in the navigation subsystem of each GPS space vehicle. Not only must the CS perform the upload function but the parameters supplied by the CS must not degrade the level of user navigation accuracy by more than 12 feet. That is, the navigation parameters (principally satellite ephemerides and satellite clock correction factors) provided by the CS must contribute no more than 12 feet (one sigma) to the User Equivalent Range Error (UERE)[2] budget.

[1] SS-GPS-101: System Specification for the Global Positioning System

[2] The reader is referred to Part II, Volume A of this technical report for a detailed discussion of UERE.

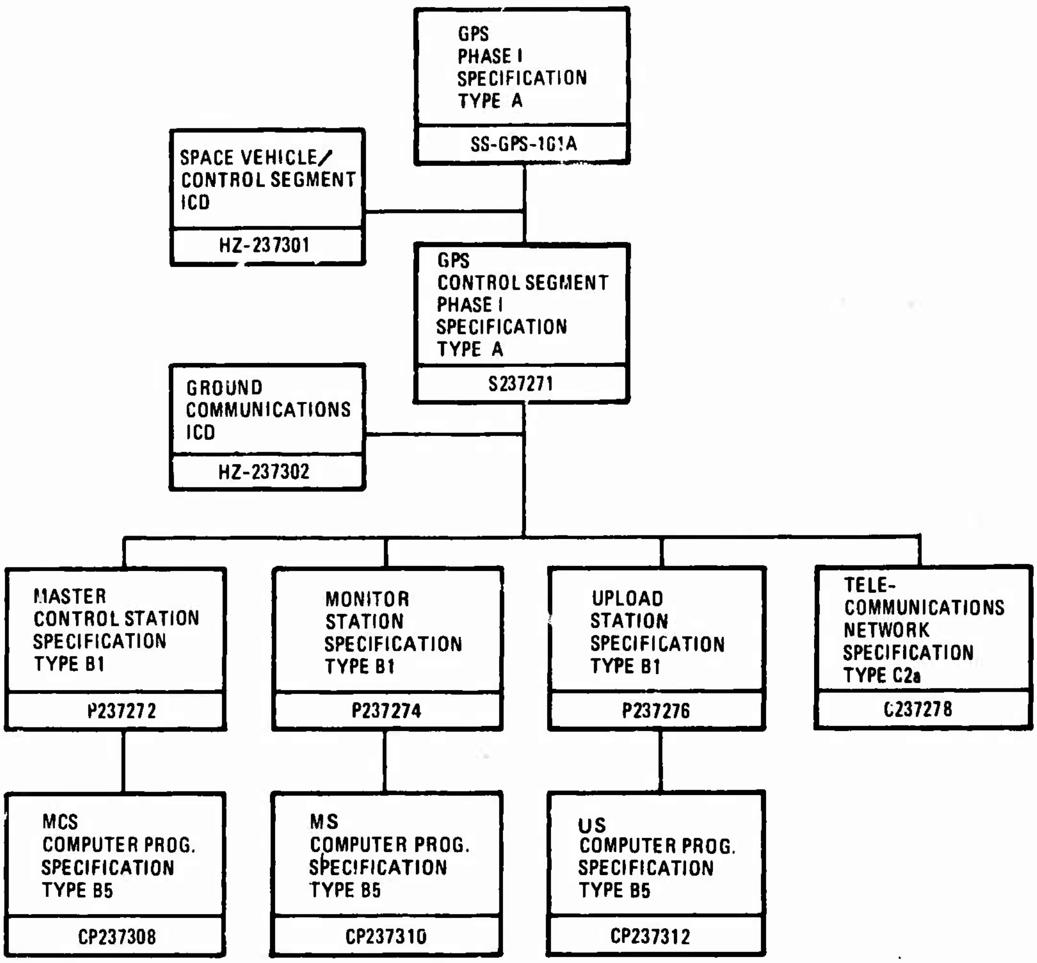


Figure 2-1 GPS Control Segment Configuration Baseline

Updating of the space vehicles' navigation subsystems with navigation parameters having the required accuracy will be accomplished by the CS through its performance of the following top-level functions:

- Exercise of CS operations control
- Navigation data collection
- Navigation data processing
- Space vehicle navigation subsystem control
- System test/calibration/maintenance

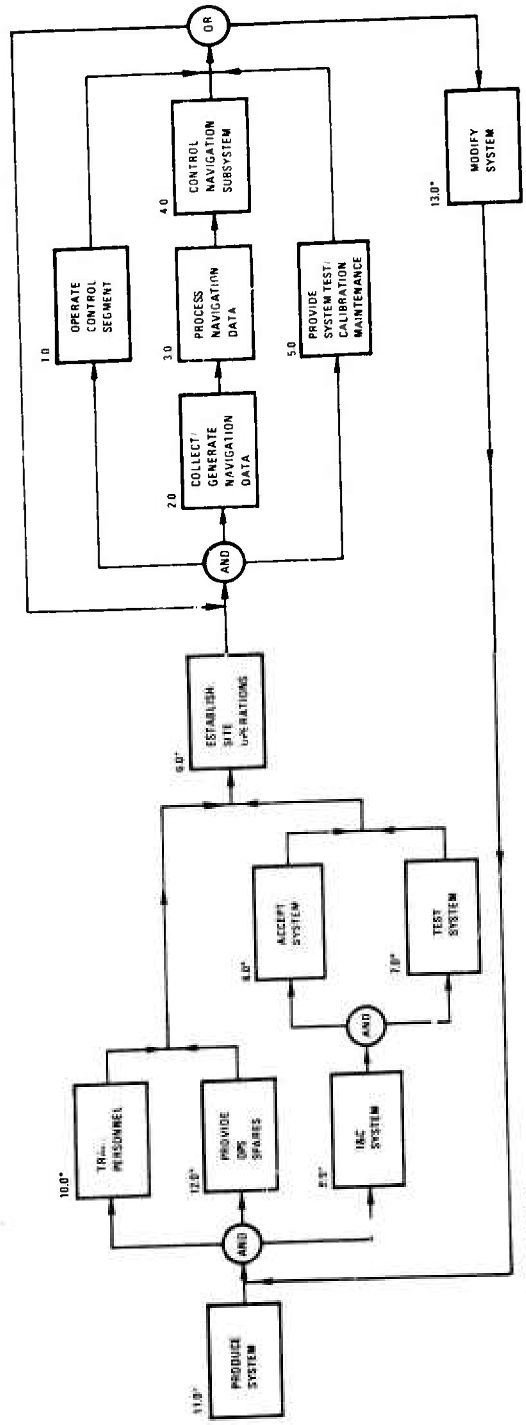
(Before proceeding, the term "navigation data" requires clarification. To a GPS user, navigation data is the data he extracts from the signals he receives from the GPS space vehicles and uses to navigate/locate himself. In the context of CS functions, navigation data is the sum total of information derived from satellite tracking, meteorological monitoring, etc, that is convolved to determine precise satellite ephemerides and clock corrections which, in turn, constitute the update message to the space vehicles.)

Figure 2-2 is a top-level functional flow block diagram (FFBD) for the CS showing the relationship of the five functions shown above to the balance of functions involved in the implementation and operation of the CS. Figures 2-3 to 2-7 are first-level FFBDs for each of the mission-related, top-level functions. Each of the top and first-level functions pictured in the figures are described briefly below. The descriptions are paraphrased directly from the Control Segment specification in order to convey the diversity of requirements levied on the CS and which must be satisfied by the hardware/software configurations documented in this Systems Analysis Report.

2.1.1 Control Segment Operations

The Control Segment shall be designed to be operated under normal conditions by 15 personnel at the MCS and 2 personnel at the US. Monitor stations shall be designed for unattended operations. Operational schedules, operator control and display, ground communications, segment status monitoring, and segment initialization and recovery shall be provided in support of this function.

- Segment Initialization and Recovery. The CS shall be designed to permit initiation from a cold start or recovery from a fault condition within 60 minutes.
- System Scheduling. The CS shall schedule segment resources for all system functions. The schedule shall be generated weekly, updated daily, and shall contain all data required by testing, operations, and maintenance personnel to plan their activities. The system schedule shall support the segment



*NO SUBSEQUENT LEVEL DEVELOPED

Figure 2-2 Control Segment Top Level Functional Flow Block Diagram

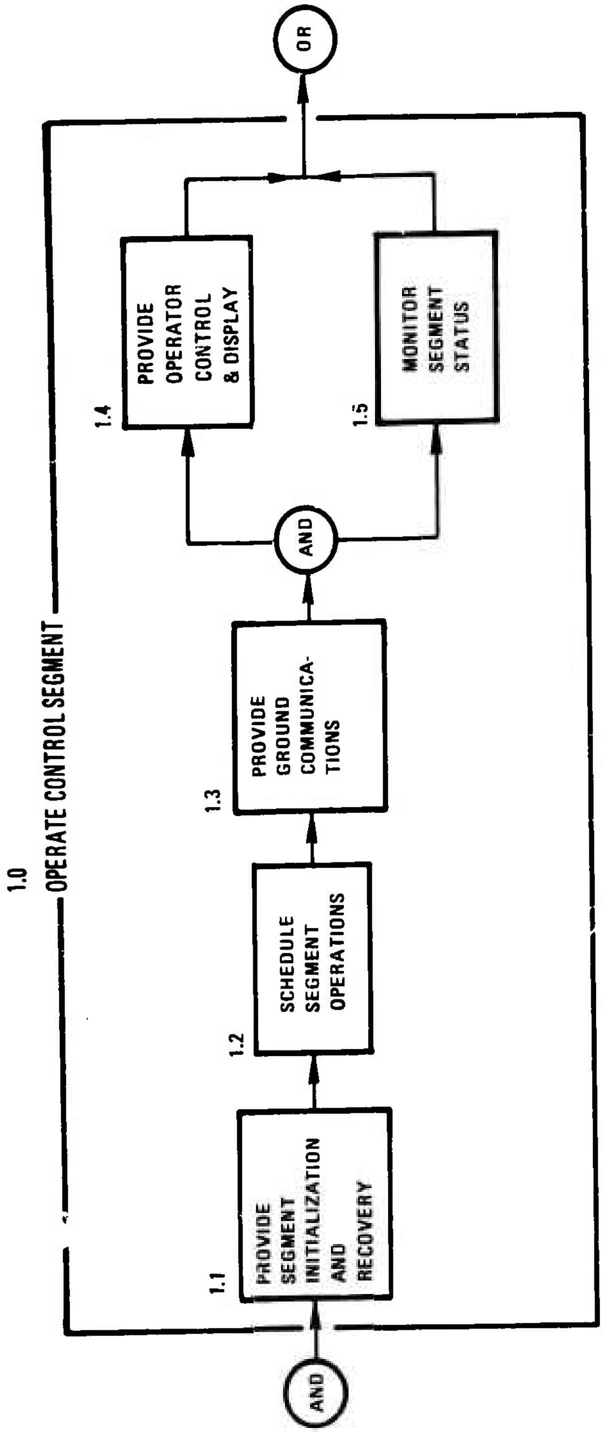


Figure 2-3 Control Segment Operations Control First Level

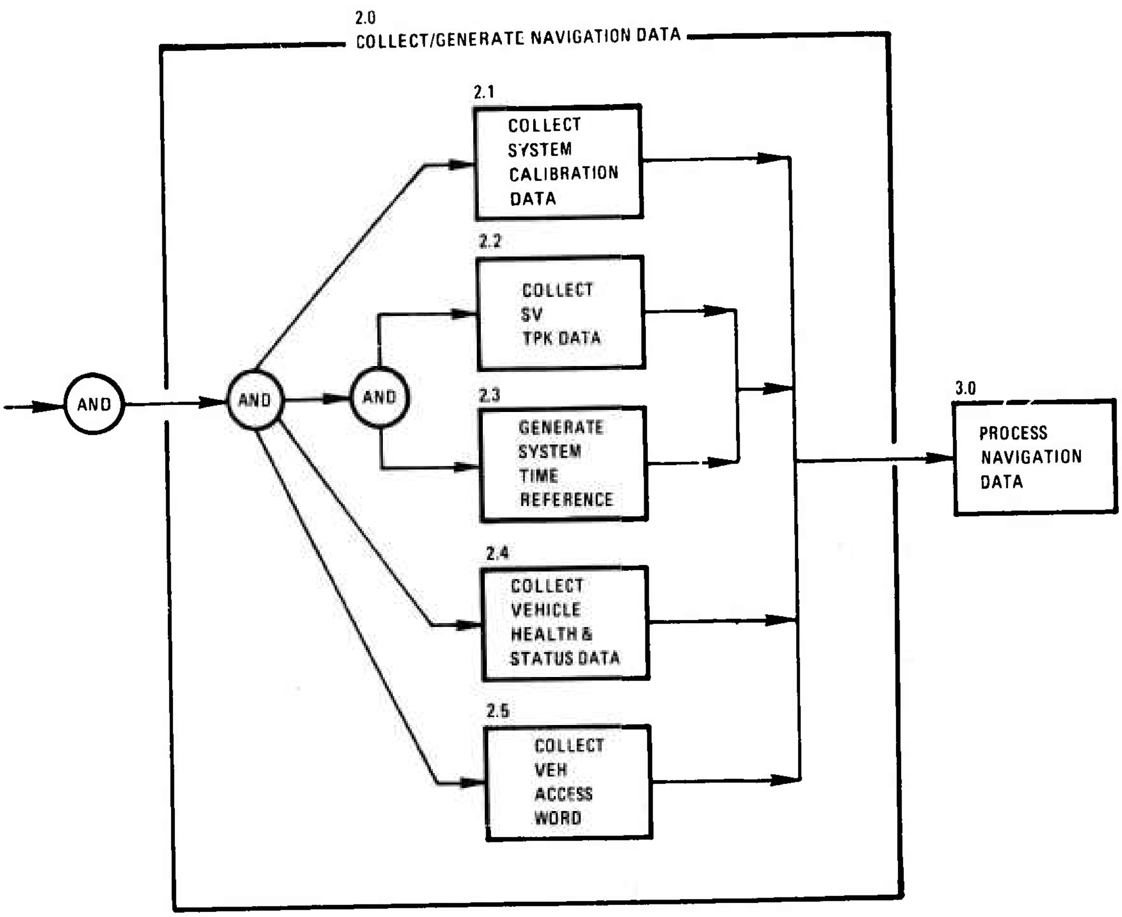


Figure 2-4 Navigation Data Collection

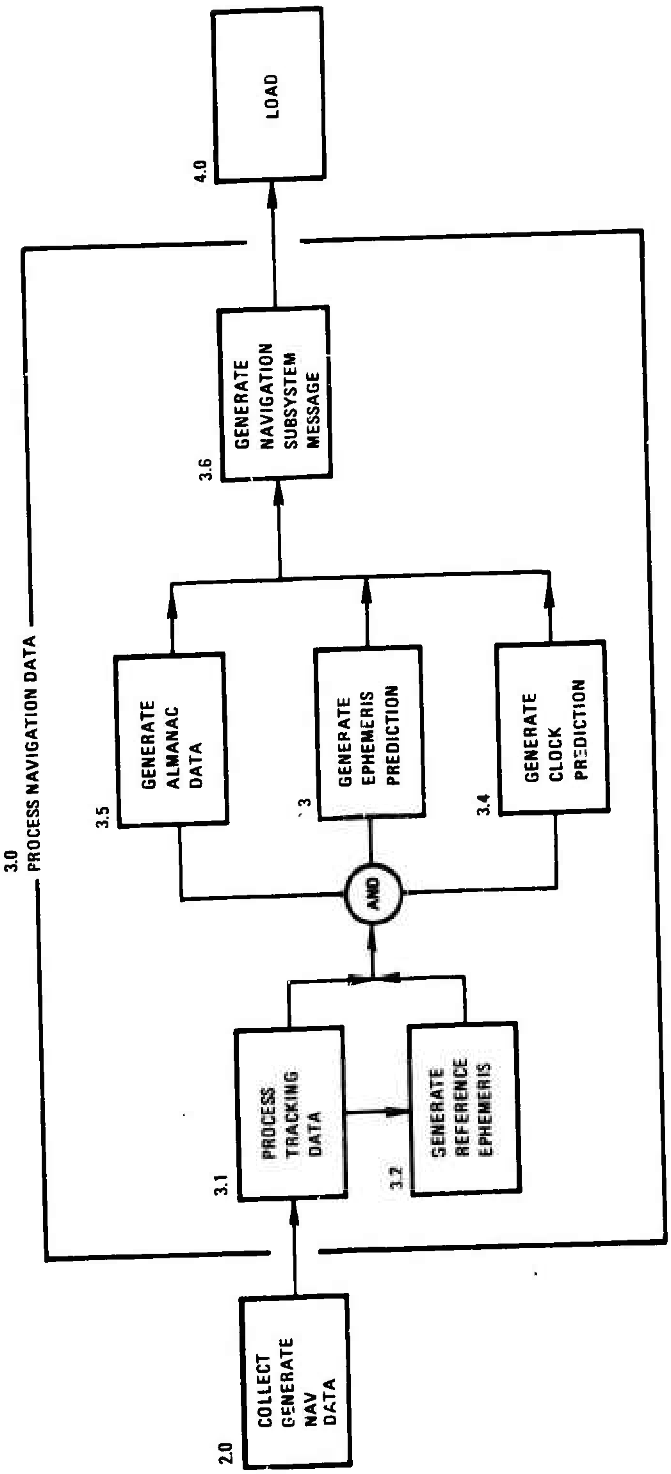


Figure 2-5 Navigation Data Processing

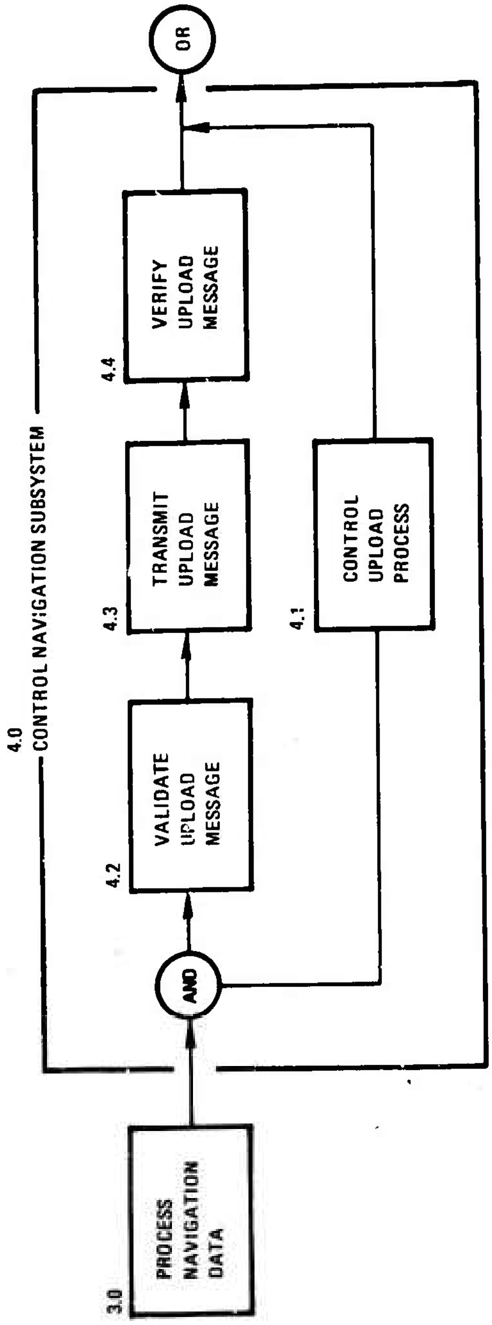


Figure 2-6 Space Vehicle Navigation Subsystem Control

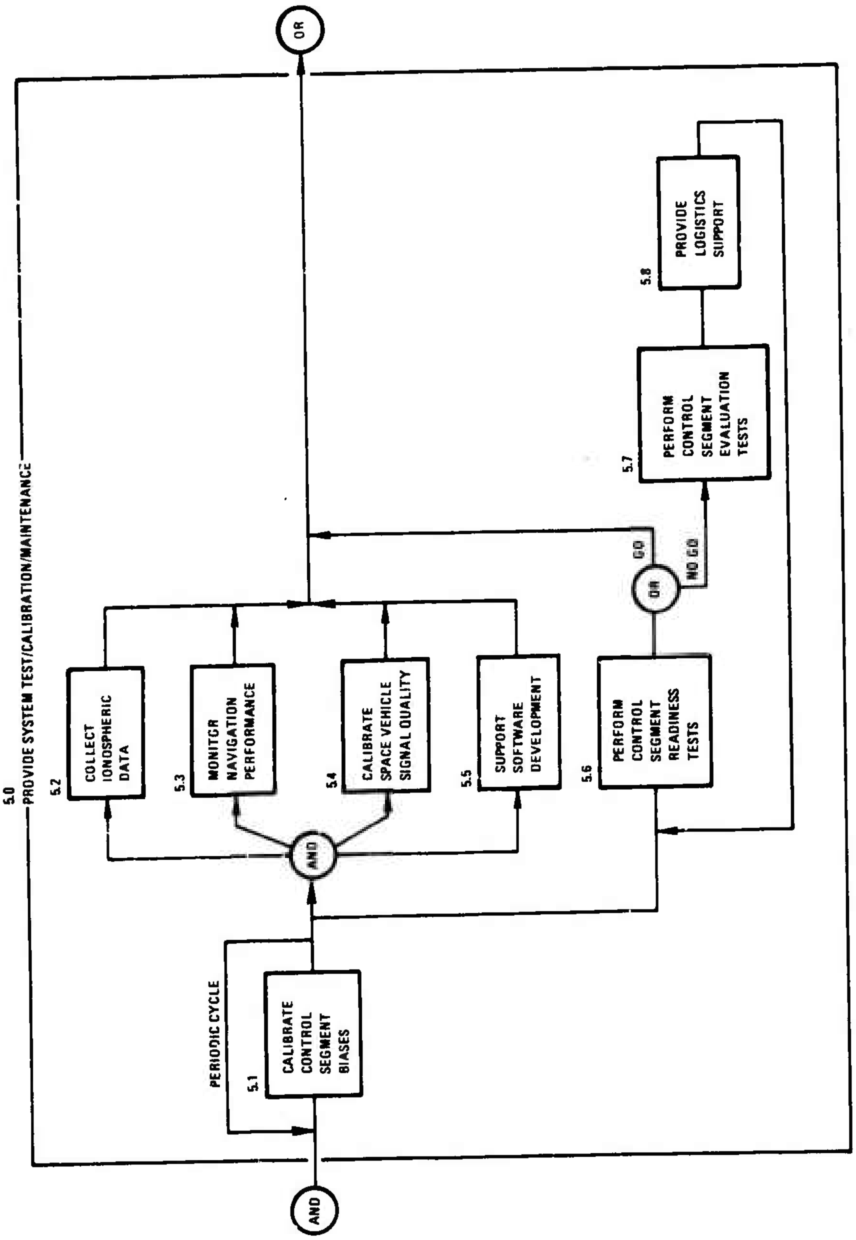


Figure 2-7 System Test/Calibration/Navigation

control function in scheduling SV tracking data collection, SV navigation subsystem control, and navigation message generation.

- Communications Function. The communications function shall be capable of controlling and implementing all data communications between the master control station and the following remote stations:

    a. Monitor stations

    b. Upload stations

    c. Satellite Control Facility

    d. Remote computing facility

    This function shall include the establishment and maintenance of communications control between the remote stations and MCS, the transmission of data messages from the MCS to the remote stations, and the reception of data messages at the MCS from the remote stations. The communications function shall be capable of supporting synchronous data transmission in support of a minimum of five full duplex 2400 bps commercial data lines between the master control station and the monitor and upload stations and the AFSCF. The communications interface between the remote computing facility and the master control station shall be via half the duplex dial-up commercial voice frequency lines. All operational data transmissions shall include error protection to ensure an undetected error rate of 10^{-10} per day over unconditioned lines. In support of the segment maintenance function, the communication function shall provide for alternate voice order-wire and administrative text transmission between CS operating locations and personnel.

- Display and Control Function. The CS shall be designed to provide efficient interaction between operations personnel, computer programs and segment elements. Control and display functions shall be implemented through the use of commercially available computer peripheral equipment. To the largest degree possible, control of the system shall be effected by operator selection of displayed control alternatives.

- Status Monitoring Function. The CS shall be designed to provide on-line monitoring of the status of all critical segment functions and elements. Current status information shall be summarized and displayed to segment operators. Abnormal status conditions shall also be displayed to the segment operators. Detailed status data shall be available upon operator request.

2.1.2 Navigation Data Collection. The CS shall collect and maintain in a central data base all data required to support CS operations, navigation processing, SV navigation subsystem control, and system testing. The CS data base shall support segment operations, personnel and computer programs. Data to be collected and maintained is defined in the following:

- System Calibration Data. The CS shall provide for storage, retrieval and processing of system calibration data. This data shall be generated off-line, periodically updated, and shall include station locations, station range biases, space vehicle transmitter biases, geopotential coefficients, etc.

- Space Vehicle Tracking Data. The CS shall be capable of collecting and processing tracking data from up to twelve (12) space vehicles and from its own ground environment. Data to be collected shall include as a minimum:

  a. L1, P-channel pseudo-range data

  b. L2, P-channel pseudo-range data

  c. Meteorological data

Each monitor station shall be capable of collecting and time tagging data from at least four (4) SVs concurrently at sampling rates up to one sample per 15 seconds.

- System Time Standard. The CS shall maintain the GPS system time synchronized to within 100 microseconds of international time as maintained by the Naval Observatory. Monitor station and space vehicle clocks shall be synchronized to GPS system time at all times by means of bias corrections maintained at the master control station. The CS shall be capable of physically resetting all system clocks to within 10 nanoseconds of the system time standard.

- Space Vehicle Health and Status Data. The CS shall be capable of analyzing SV health and status data by means of data and support computer programs.

- Space Vehicle Access Key. The CS shall be capable of storage, retrieval, and processing of a minimum of 20 access keys for each active SV. CS design shall provide for handling the SV key as classified material. Key material shall be generated and provided by the AFSCF.

2.1.3 Navigation Data Processing. The navigation data processing function shall generate ephemeris, clock, almanac, and SV navigation subsystem control data. This function shall operate on the L-band tracking data acquired by the monitor stations, and the reference

ephemeris data provided by the RCF to produce the update data messages. This process shall include the subfunctions defined below.

- Tracking Data Preprocessing. Raw tracking data shall be processed to provide a minimum to 50 pseudorange data points per orbit per SV with an expected one sigma uncertainty of 1.5 meters. This data shall be used in the ephemeris correction process and shall also be provided to NWL once every 7 days in support of the reference ephemeris generation function.

- Reference Ephemeris Generation. Reference ephemerides shall be generated for each SV by the Naval Weapons Laboratory, Dahlgren, Virginia. This function shall satisfy the following requirements:

  a. Data for up to 12 SVs shall be maintained.

  b. The CS shall provide to NWL accumulated tracking data once every 7 days.

  c. NWL shall update and return reference ephemerides to the CS within 3 days of receipt of current tracking data.

  d. Each set of reference ephemerides shall be valid for 15 days.

- SV Ephemeris Prediction. The CS shall generate refined ephemeris predictions using preprocessed tracking data for storage in each SV with the following performance characteristics:

  a. Number of SV: Up to twelve

  b. Period of prediction: Two days minimum

  c. Response time: One hour from receipt of last valid tracking data sample.

- SV Clock Prediction. The CS shall generate SV clock state predictions to be stored in the navigation payload and transmitted to users as part of the users' navigation data. Clock state predictions shall include relativity effects.

- Almanac Data Generation. The CS shall generate and maintain a data base containing almanac data for all active SVs. Uses of this data shall include:

  a. Scheduling SV upload functions and generating antenna pointing data in support of these functions.

  b. Scheduling SV tracking functions and generating the receiver acquisition data in support of these functions.

c. Construction of reference data fields in navigation data formats

- Upload Message Generation. The CS shall be capable of generating upload message formats for transmission to the upload station (US). These messages shall be used to:

  a. Update the SV navigation subsystem data.

  b. Control the SV navigation subsystem.

  In addition, the CS shall be capable of providing navigation update data to the AFSCF for backup upload functions.

2.1.8 Space Vehicle Navigation Subsystem Control. The CS shall be capable of loading and controlling the SV navigation subsystem. The phase I CS design shall be optimized for collocation of the MCS and US elements but shall provide for future relocation of the US to a remote location, and the addition of a second remote US. This function shall include control of the uploading process, validation of the upload message prior to transmission, transmission of the upload message and verification of proper loading.

- Navigation Upload Control. Control of the upload function shall be designed to minimize operator intervention so as to achieve a complete payload update within 10 minutes. Manual backup capability shall be provided for all critical functions.

- Upload Message Validation. Each upload message shall be validated prior to transmission to insure that the information, when accepted by the SV, will result in satisfactory navigation data. The validation process will include as a minimum the following subfunctions:

  a. Generation of command data in the exact form in which it is to be transmitted.

  b. Processing of the message in a manner which simulates the SV/user navigation process so as to generate a navigation data format.

  c. Analysis of the resulting navigation data formats.

  The results of the validation process will be displayed to the segment operator.

- Upload Message Transmission. The control segment shall provide capabilities for transmission in a SGLS compatible format of the navigation subsystem upload message to each space vehicle. The upload link power budget and verification technique shall support an undetected bit error rate of 10^{-15} when the nominal upload link error rate is 10^{-5}.

- Upload Verification and Retry. The control segment shall verify that the SV has properly received all navigation subsystem control messages. Verification shall be accomplished through analysis of verification status data contained in the L-band navigation data. Each upload message shall be verified on a block by block basis. Blocks which are not properly verified shall be automatically retransmitted. The number of automatic retransmissions shall be an operator control variable.

2.1.5 System Test/Calibration/Maintenance. The control segment shall be designed to support system test, calibration, and maintenance as defined below.

- Control Segment Calibration. In support of the navigation data collection function, the control segment shall be capable of periodically calibrating segment biases that degrade segment performance. Wherever practical this capability shall be designed into the system so as to minimize operator attention.

  It shall be possible to perform this calibration sufficiently often to ensure, for example, that the group delay uncertainties between the station reference location and the actual location of the receiver correlation detector shall not exceed 2 nanoseconds. Predictable delay variations due to time, temperature, signal strength, or other measurable parameters shall be modeled as required to meet this requirement.

- Ionospheric Data Collection. The control segment shall provide for collection and storage of ionospheric data required to evaluate potential single-frequency ionospheric correction models. This data base shall include as a minimum for each observation: integrated electron density; observing station latitude and longitude; satellite azimuth and elevation; GMT time of day; day of year; year.

  Ionospheric data shall be converted to engineering units, formatted for convenient off-line batch processing, and stored on tape. It shall be possible to produce printed hard copy of data currently in storage or of data previously recorded.

- Navigation Performance Evaluation. The CS shall provide operations personnel with information required to monitor and evaluate GPS navigation performance. This information shall be derived from the navigation data base and shall be available to operations personnel on demand. Critical parameters shall be recorded for use in off-line analysis of user navigation tests. As a minimum, this function shall provide:

a. A measure of the residuals between known monitor station locations and locations determined by processing received SV L-band signal.

b. A measure of the residuals between predicted satellite ephemerides and preprocessed tracking data.

c. A measure of the residuals between raw tracking data and smoothed tracking data.

d. A measure of the error between the latest observed SV clock state and the state predicted by clock parameters in the navigation data frame.

e. A measure of residuals between the estimate of SV ephemerides at the latest epoch and the ephemerides which were predicted for that epoch 24, 48, and 120 hours before.

f. A measure of the residuals between the estimate of SV clock state at the latest epoch and the state which was predicted for that epoch 1, 4, 12 and 24 hours before.

g. A measure of the physical, ie, uncorrected, synchronization error between the GPS time standard and all MS and SV clocks.

- Space Vehicle Signal Quality Monitoring. In support of the Phase I GPS test and evaluation requirements, the CS shall provide capability for measuring the quality of the signal received from each space vehicle. Wherever practical the instrumentation necessary for these measurements shall be included in the CS design, and the measurement results shall be available to system operators upon request.

- Support Software Development. The CS shall provide the hardware and software necessary to support field modification and development of the operational computer programs. It shall be possible to schedule this function so as not to interfere or degrade normally scheduled operational functions.

- Segment Readiness Testing. The control segment shall provide, in support of the operations function, the capability to rapidly determine the readiness of the segment to support its mission. This function shall exercise all elements of the segment while in an operational configuration, independent of the space vehicles. It shall be possible to initiate this test function from an operators console. Test results shall be provided in the form of a go, no-go indication within 5 minutes. No other operator actions shall be required to initiate and complete this function. Lower level tests, ie, upload and monitor station readiness

tests shall also be provided. These tests shall be initiated in the various maintenance areas in order to rapidly isolate a fault detected at the segment level.

- Segment Evaluation Testing. The CS design shall provide, in support of the system maintenance function, the capability for periodic performance evaluation of critical segment parameters. Performance of these tests shall be classified as maintenance actions and shall require the attention of maintenance personnel. The control segment design shall satisfy the following requirements in support of this function.

  It shall be possible to complete all scheduled periodic maintenance without connecting or disconnecting cables or equipment normally required for operational support.

  Wherever it is necessary to connect external equipment, appropriate test connectors shall be provided. These test connections shall be isolated from operational circuits so that connections or disconnections do not affect the operating characteristics of the system.

- Logistics Support. The CS shall provide all spares and repair facilities required to restore failed equipment, or equipment exhibiting degraded performance, to a state of operational readiness.

2.2 CONTROL SEGMENT INTERFACE REQUIREMENTS

To fully implement the functions described above, the CS must establish a number of external interfaces, viz, with the GPS space vehicles[1], with the remote computing facility[2] and with the AFSCF[2]. Each of these interfaces is addressed below.

2.2.1 S-Band Uplink to the Space Vehicle(s)

The CS must establish an S-band RF uplink with the GPS space vehicles. This uplink is used principally to refresh the vehicles' navigation data bases by periodically transmitting navigation payload updating messages to the vehicles. The link is also used for limited, clear

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[1] Refer to the interface control drawing (ICD) for the space vehicle/control segment interface (ICD No. HZ-237301) for the details of this interface.

[2] The ground communications ICD (HZ-237302) and Section 3.6: Control Segment Telecommunications address these interfaces in detail.

(ie, not encrypted) commanding of the vehicles and for transmitting processing instructions to the payload. The principal characteristics of this uplink interface are:

Carrier frequency	One (as specified) of the 20 SGLS channels, 1.75 GHz to 1.85 GHz
Polarization	Right-hand circular
Modulation format	FSK, SGLS-compatible (1, 0, S)
Command/data rate	1000 bps
Bit error probability	Less than 10^{-5}

2.2.2 L-Band Downlink from the Space Vehicle(s)

The CS must establish an S-band RF downlink with the space vehicles. This downlink serves to convey upload verification data and "tracking" data to the CS. The principal characteristics of this downlink interface are:

Carrier frequencies	1575 MHz (nom), "L1" 1250 MHz (nom), "L2"
Polarization	Right-hand circular
Modulation format	Quadriphase
Modulation, 0°/180°	10.23 Mbps pseudorandom protected code with 50 bps data modulo-2 added ("P-code" and "P-data")
90°/270°	1.023 Mbps pseudorandom clear code with 40 bps data modulo-2 added ("C-code" and "C-data")
Received signal power, minimum	-130.0 dBm for L1-C -133.0 dBm for L1-P -136.0 dBm for L2-P (C-signal not modulated on L2)

2.2.3 Control Segment/Remote Computing Facility Interface

The CS provides the RCF with "raw" tracking/navigation data gathered from the MS and smoothed by the MCS. The RCF computes reference ephemerides from this data input for the GPS space vehicles and system calibration parameters and returns this data to the CS. This interface will be implemented via the CS telecommunications network using a manual dial-up link (MDL) over a voice-grade, two-wire

circuit. The connection of the telecommunications network to the CS shall comply with industry standards, in particular EIA RS-232-C.

2.2.4 Control Segment/AFSCF Interface

The AFSCF supports the space vehicle upload function of the CS by providing "keys" which are forwarded to the US to allow it to communicate with the otherwise secure space vehicles. The AFSCF and CS also exchange system/space vehicle control/coordination data -- for example, the CS provides the AFSCF with upload messages in the event the AFSCF is to serve as a backup for the US. This interface will also be implemented with a MDL.

2.3 CONTROL SEGMENT OPERABILITY REQUIREMENTS

It is important that the CS not only perform the functions, and establish the interfaces, described above but that it provide a high level of operability as well. That is, the CS must incorporate designs/components having sufficient reliability and maintainability to meet GPS/CS availability goals. Moreover, the CS equipment must be designed in accordance with accepted human engineering and safety engineering practices in order to provide an environment for CS personnel which promotes the safe, reliable, error-free operation of the segment.

2.3.1 Control Segment Availability

Control Segment Availability is defined as the probability of successfully uploading the GPS space vehicles such that the user segment is provided navigation signals within the limits of the UERE budget. The quantitative requirements for the Phase I configuration shall be as follows:

> Based upon a 7 day per week, 24-hour per day operation, and recognizing the constraints imposed by the operational time lines, the Control Segment shall provide no less than a 70 percent probability that all space vehicles are properly uploaded, as they "enter" the test area given the satellites are performing in accordance with their specifications.

To assure that the overall Control Segment will demonstrate at least a 70 percent probability of success, the individual functional areas should exhibit probabilities of success exceeding those tabulated below:

Functional Area	Probability of Success
Monitor Station	0.90
Upload Station	0.92
MCS Computer	0.90
Telecommunications Network	0.94
Overall Control Segment	0.70

2.3.2 Human/Safety Engineering Considerations

a. Human Performance/Human Engineering. The CS equipment is to be designed to provide a work environment which fosters effective work patterns and minimizes discomfort, distraction, or other factors which degrade human performance or increases the possibility of error. The design and development of the ground equipment is to be in accordance with the principles, procedures, and criteria of human engineering established by MIL-STD-1472A. The resulting man/machine combination should meet system objectives in an efficient and safe manner. All new or modified equipment is to incorporate human engineering criteria specified in paragraphs 5.1 through 5.9.19 of MIL-STD-1472A.

b. Safety. The design of the CS and its elements should provide the maximum protection against personnel injury and equipment damage. Systems safety engineering principles are to be applied throughout the design-development, manufacture, test, installation, checkout, and operation of the ground equipment in accordance with the general requirements of MIL-STD-882, all applicable criteria of MIL-STD-1472A and MIL-STD-454C, Requirement 1. CS personnel are to be protected from hazardous electromagnetic radiation in accordance with the criteria and requirements of MIL-R-9673B.

2.4 ALLOCATION OF CONTROL SEGMENT REQUIREMENTS

In Section 1 the four major elements of the control segment are identified as:

a. The master control station (MCS)

b. The monitor station (MS)

c. The upload stations (US)

d. The telecommunications network (TN)

Within each of these elements reside personnel and major components of hardware and software (the TN is hardware only and the MS operates unattended). Table 2-1 serves to allocate the CS functional requirements to the hardware, software and personnel of each element. Table 2-2 allocates interface requirements, and Table 2-3 apportions reliability and maintainability requirements.

TABLE 2-2

ALLOCATION OF CONTROL SEGMENT INTERFACE REQUIREMENTS

INTERFACE REQUIREMENT	CONTROL SEGMENT ELEMENT			
	MASTER CONTROL STATION	MONITOR STATIONS	UPLOAD STATION	TELECOMMUNICATIONS ELEMENT
UPLINK TO SPACE VEHICLE			X	
DOWNLINK FROM SPACE VEHICLE		X	X	
CS/AFSCF INTERFACE	X			X
CS/RCF INTERFACE	X			X

TABLE 2-3

ALLOCATION OF CONTROL SEGMENT RELIABILITY & MAINTAINABILITY REQUIREMENTS

CONTROL SEGMENT ELEMENT	RELIABILITY (FAILURES PER 10^6 HOURS)	MAINTAINABILITY (MEAN-TIME-TO-RESTORE, HOURS)
MASTER CONTROL STATION	20,000	4.05
MONITOR STATION	5,000	17.39
UPLOAD STATION	10,000	6.95
TELECOMMUNICATIONS ELEMENT	15,000	4.11

FUNCTION	Master Control Station			Upload Station	
	HARDWARE CI NO. 237273	SOFTWARE CPCI NO. 237309	PERSONNEL	HARDWARE CI NO. 237277	SOFTWARE CPCI NO. 23731
Control Segment Operations					
• Segment Initialization and Recovery		X	X		
• System Scheduling		X	X		
• Communications Function		X	X		X
• Display and Control Function	X	X		X	X
• Status Monitoring Function	X	X	X	X	X
Navigation Data Collection					
• System Calibration Data		X			
• Space Vehicle Tracking Data				X	X
• System Time Standard	X	X			
• Space Vehicle Health and Status Data		X			
• Space Vehicle Access Key		X			
Navigation Data Processing					
• Tracking Data Preprocessing		X			
• Reference Ephemeris Generation		X			
• SV Ephemeris Prediction		X			
• SV Clock Prediction		X			
• Almanac Data Generation		X			
• Upload Message Generation		X			
Space Vehicle Navigation Subsystem Control					
• Navigation Upload Control		X	X		X
• Upload Message Validation		X			X
• Upload Message Transmission				X	X
• Upload Verification and Retry				X	X
System Test/Calibration/Maintenance					
• Control Segment Calibration				X	
• Ionospheric Data Collection		X			
• Navigation Performance Evaluation		X			X
• Space Vehicle Signal Quality Monitoring				X	X
• Support Software Development	X	X			
• Segment Readiness Testing	X	X		X	X
• Segment Evaluation Testing	X	X	X	X	X
• Logistics Support			X		

	Upload Station			Monitor Station			Tele Com
EL	HARDWARE CI NO. 237277	SOFTWARE CPCI NO. 237313	PERSONNEL	HARDWARE CI NO. 237275	SOFTWARE CPCI NO. 237311	PERSONNEL	CI NO. 237279
			X				
	 X X	X X X	 X	 X X	X X X		X
	X	X		X	X		
		X	X				
	 X X	X X X					
	X		X	X		X	
	 X	X X			X		
	X X	X X		X X	X X		

Table 2-1 Allocation of Control Segment Functional Requirement

SECTION 3

CONTROL SEGMENT HARDWARE AND SOFTWARE

The purpose of this section is to present the baseline configuration of CS hardware and software that has been developed (and continues to be refined) to meet the requirements established in the preceding section. To present the CS baseline, this section offers first an overview of the entire segment [to provide the reader with a "feel"] illustrating the inter-relationship of CS elements, their deployment and their prime roles in support of the GPS mission. The elements are then described individually in the following order:

a. Monitor Stations (MS)

b. Master Control Station (MCS)

c. Upload Station (US)

d. Telecommunications Network (TN)

Within each description of a CS element the requirements levied on that specific element are reviewed, hardware and software configurations addressing the requirements are presented at several levels of detail and, finally, the physical arrangement (eg, rack elevations and floor plans) of the element is provided to complete the description.

3.1 CONTROL SEGMENT CONFIGURATION OVERVIEW

Each CS element comprises a number of major components and within each major component reside one or more pieces of equipment, chassis, etc. In this overview the elements are examined only to the major component level -- subsequent descriptions of the individual element proceed below the major component level. Figure 3-1 is an end-to-end block diagram of the CS showing the interconnection of all the major components and interfaces of the CS. To the left of the diagram are the three Monitor Stations and their interfaces with the GPS space vehicles. Central to the diagram is the MCS, and, to the right is the US, again providing the CS to an interface to the space vehicles. Connecting the MSs to the MCS and the MCS to the US is the TN. In addition (but not shown in the figure), the TN implements the MCS interfaces with the AFSCF and RCF.

The shaded arrow across the breadth of the diagram represents the prime data flow path through the CS. All hardware, software and

personnel are subservient to the maintenance and optimization of this data flow. A simplified illustration of the data flow is given in Figure 3-2. Note in this figure the identification of specific functions with specific elements, viz:

Monitor Station	COLLECT navigation data
Master Control Station	PROCESS navigation data
Upload Station	UPLOAD navigation data

Albeit Figure 3-2 may greatly oversimplify the structure of the CS, the COLLECT -- PROCESS -- UPLOAD, MS -- MCS -- US relationship is a convenient point of departure toward understanding the more detailed function/equipment relationships to follow.

3.2 CONTROL SEGMENT DEPLOYMENT

The MCS AND US will be collocated at Vandenberg Air Force Base, California within the existing building 22104. This building was formerly the Prelort Building for the Vandenberg Tracking Station (VTS), part of the Air Force Satellite Control Facility (AFSCF) ground system. The building 22104 complex is shown in Figure 3-3 and its location with respect to VTS and surrounding communities is shown in Figure 3-4. The building is in a military secured area in which access can be controlled to any degree desired.

The prelort ground station (including SGLS receiving and ranging equipment, a 10 kW SGLS transmitter and a 14-foot diameter S-band antenna) has been deactivated in-place and remains in rooms 104 and 107 and the radome at the east end of building 22104. A number of rooms, however, are available at the west end of the building to house the MCS and US, including space for maintenance, technical test equipment storage, spare parts and offices and for future MCS expansion. In addition, all outside utility services needed by the MCS and US are available including water, access roads, sanitary services and outside fire protection services. Electric power is provided by the local utility company via underground cables to the substation shown in Figure 3-3. Existing personnel support facilities (ie, messing, housing, etc) provided by the host base and surrounding civilian communities are adequate to support the additional personnel needed for operation of the MCS and US.

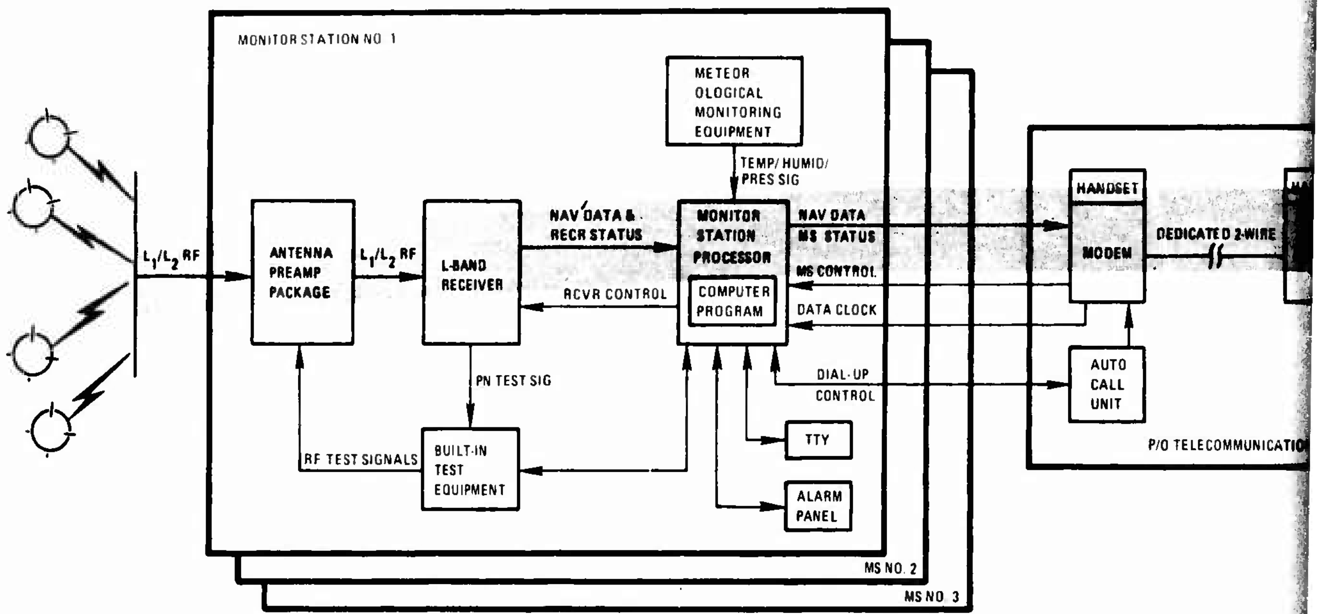
The three MS will be deployed in the following three locations:-

a. U. S. Army Fort Richardson, Alaska

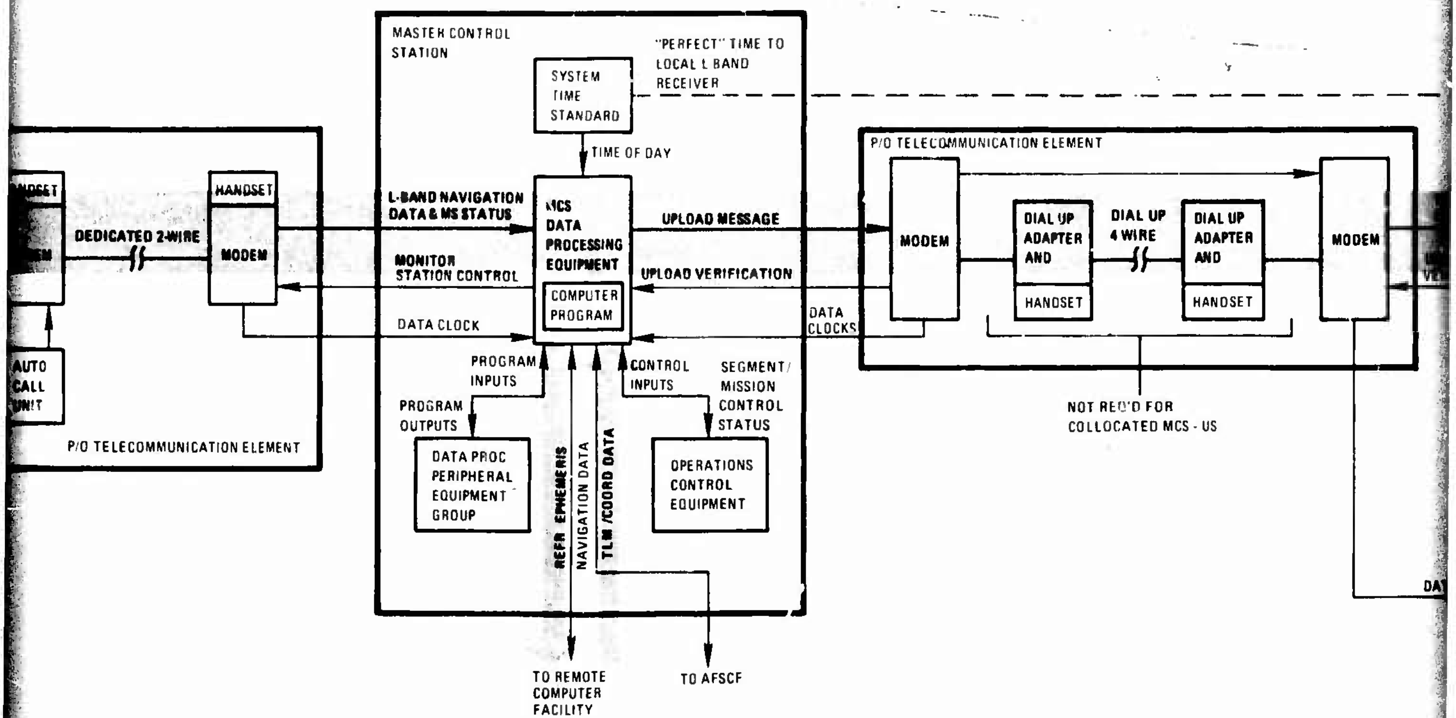
b. U. S. Naval Communications Station, Wahiawa, Oahu, Hawaii

c. Transportable to a site to be selected

The facilities identified for installation of the MS at Fort Richardson are presently used by the US Air Force 1931st Communications Group for their communications VHF transmitters and associated equipments. The facilities consist of a two story reinforced concrete building No. 35-750, a power house building No.



MONITOR STATION NO 1
METEOR OLOGICAL MONITORING EQUIPMENT
TEMP/ HUMID/ PRES SIG
L_1/L_2 RF
ANTENNA PREAMP PACKAGE
L_1/L_2 RF
L-BAND RECEIVER
NAV DATA & RECR STATUS
RCVR CONTROL
MONITOR STATION PROCESSOR
COMPUTER PROGRAM
NAV DATA
MS STATUS
MS CONTROL
DATA CLOCK
DIAL-UP CONTROL
PN TEST SIG
RF TEST SIGNALS
BUILT-IN TEST EQUIPMENT
TTY
ALARM PANEL
MS NO. 2
MS NO. 3
HANDSET
MODEM
DEDICATED 2-WIRE
AUTO CALL UNIT
P/O TELECOMMUNICATIO



MASTER CONTROL STATION
"PERFECT" TIME TO LOCAL L BAND RECEIVER
SYSTEM TIME STANDARD
TIME OF DAY
MCS DATA PROCESSING EQUIPMENT
COMPUTER PROGRAM
L-BAND NAVIGATION DATA & MS STATUS
MONITOR STATION CONTROL
DATA CLOCK
UPLOAD MESSAGE
UPLOAD VERIFICATION
DATA CLOCKS
HANDSET
MODEM
DEDICATED 2-WIRE
AUTO CALL UNIT
P/O TELECOMMUNICATION ELEMENT
PROGRAM INPUTS
PROGRAM OUTPUTS
DATA PROC PERIPHERAL EQUIPMENT GROUP
REFR EPHEMERIS
NAVIGATION DATA
TLM /COORD DATA
CONTROL INPUTS
SEGMENT/ MISSION CONTROL STATUS
OPERATIONS CONTROL EQUIPMENT
TO REMOTE COMPUTER FACILITY
TO AFSCF
P/O TELECOMMUNICATION ELEMENT
MODEM
DIAL UP ADAPTER AND
HANDSET
DIAL UP 4 WIRE
DIAL UP ADAPTER AND
HANDSET
MODEM
NOT REQ'D FOR COLLOCATED MCS - US

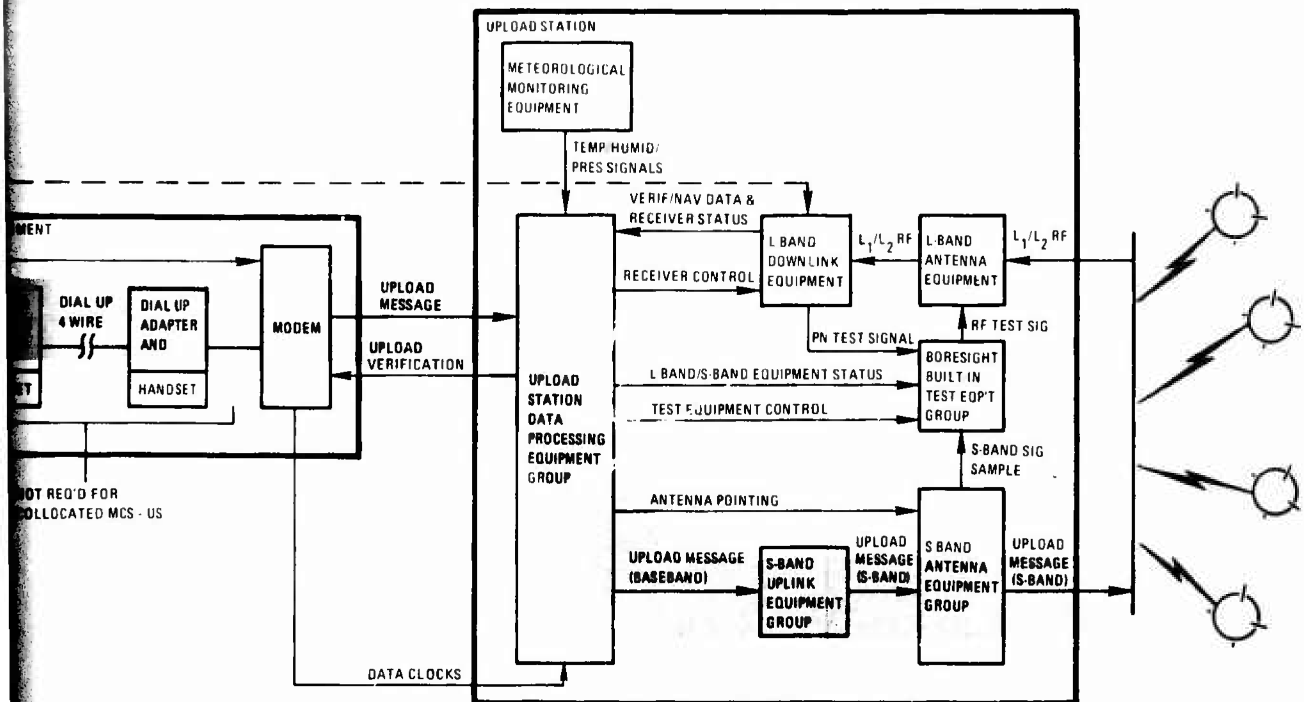


Figure 3-1 Control Segment Block Diagram

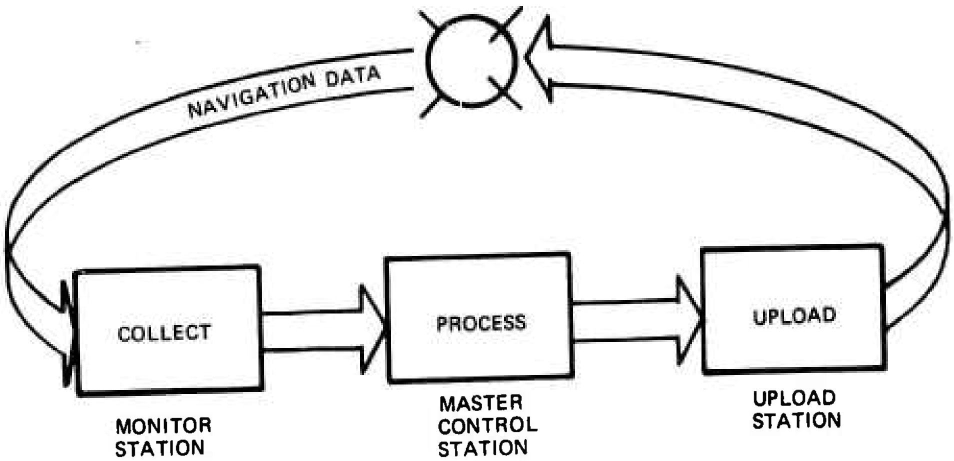


Figure 3-2 Simplified Data Flow Diagram

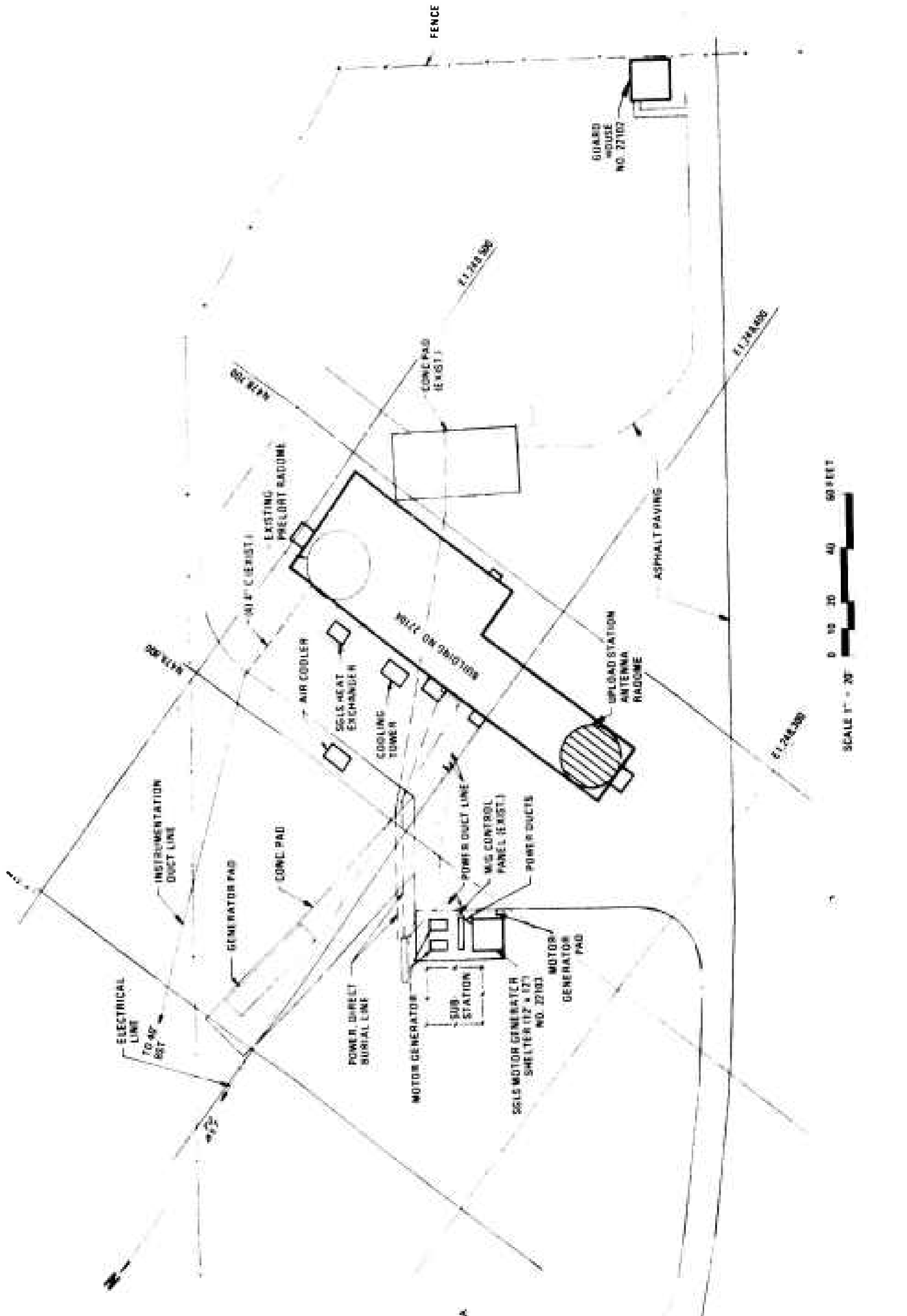


Figure 3-3 Plot Plan, Building 22104 Area

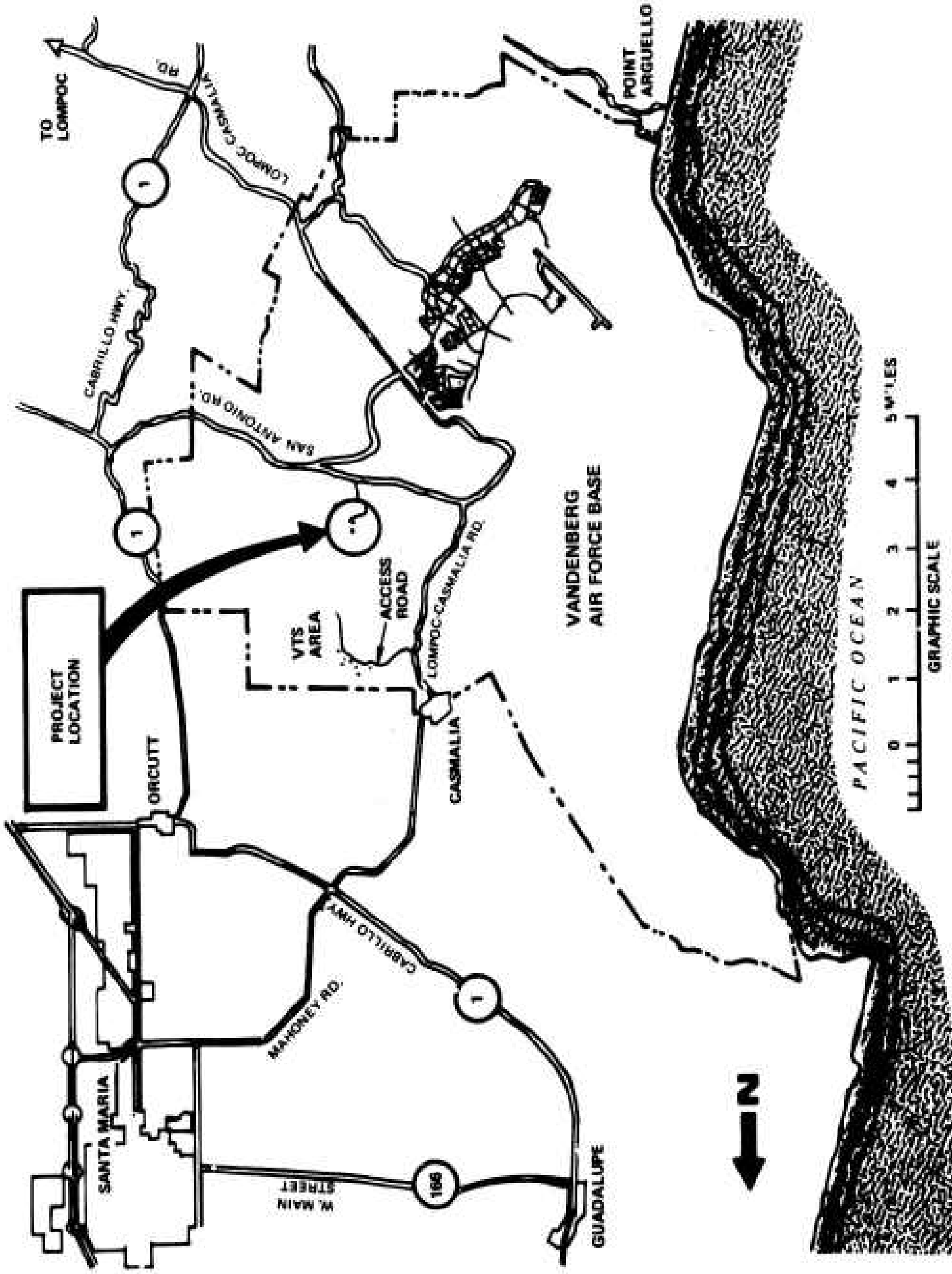


Figure 3-4 Master Control Station Locality

35-752, and a large antenna field surrounding the area. Over 3000 square feet of the main building floor area is clear of all equipment. These two buildings, while on the grounds of Fort Richardson, are facilities of the adjacent Elmendorf AFB. The MS to be located in Hawaii will be in facilities assigned to the Naval Astronautics Group (NAG) Detachment Charlie. These facilities consist of a one story building No. 387 and a roof mounted Tri-Helix transmitting antenna with a 20 ft diameter radome.

Both the Alaska and Hawaii MS will be located within military secured areas in which access can be controlled to any degree desired. The MS equipment will be integrated into the existing equipment areas at both sites and all support services, including electric power, water, sanitary and fire protection will be provided by the host facilities. In addition, the maintenance facilities at both Alaska and Hawaii are adequate to support the small additional requirements imposed by the MS.

The third MS will be transportable but will require facilities approximating those identified in Alaska and Hawaii, ie, the MS will require a sheltered environment supplied with electric power and with access to land-line communication links.

Figures 3-5 and 3-6 illustrate the relationship of the MS sites to surrounding facilities and communities in Alaska and Hawaii, respectively.

3.3 MONITOR STATION DESCRIPTION

This subsection presents the hardware and software baseline configuration for the GPS monitor stations. The configuration was assembled with both requirements and design/development costs in view -- the result being an MS configuration which meets, when evaluated analytically, the CS requirements allocated to it and which does so at a minimum cost.

3.3.1 Monitor Station Requirements

The principal function of the MS is to collect navigation data from the GPS space vehicles. In Section 2, however, a number of subsidiary functions are allocated to the MS in addition to its prime data collection function. Moreover, the MS is also allocated interface and availability requirements.

Table 3-1 restates the functional requirements levied on MS hardware and software. Referring to the table note that the MS is allocated, the functions of collecting space vehicle tracking and related data and forwarding these data to the MCS. Further, the MS is to provide operator controls and displays, to monitor its internal status and report this status to the MCS, and to support the overall CS function of system test/calibration/maintenance. This latter function will be accomplished by readiness and performance test capability and by

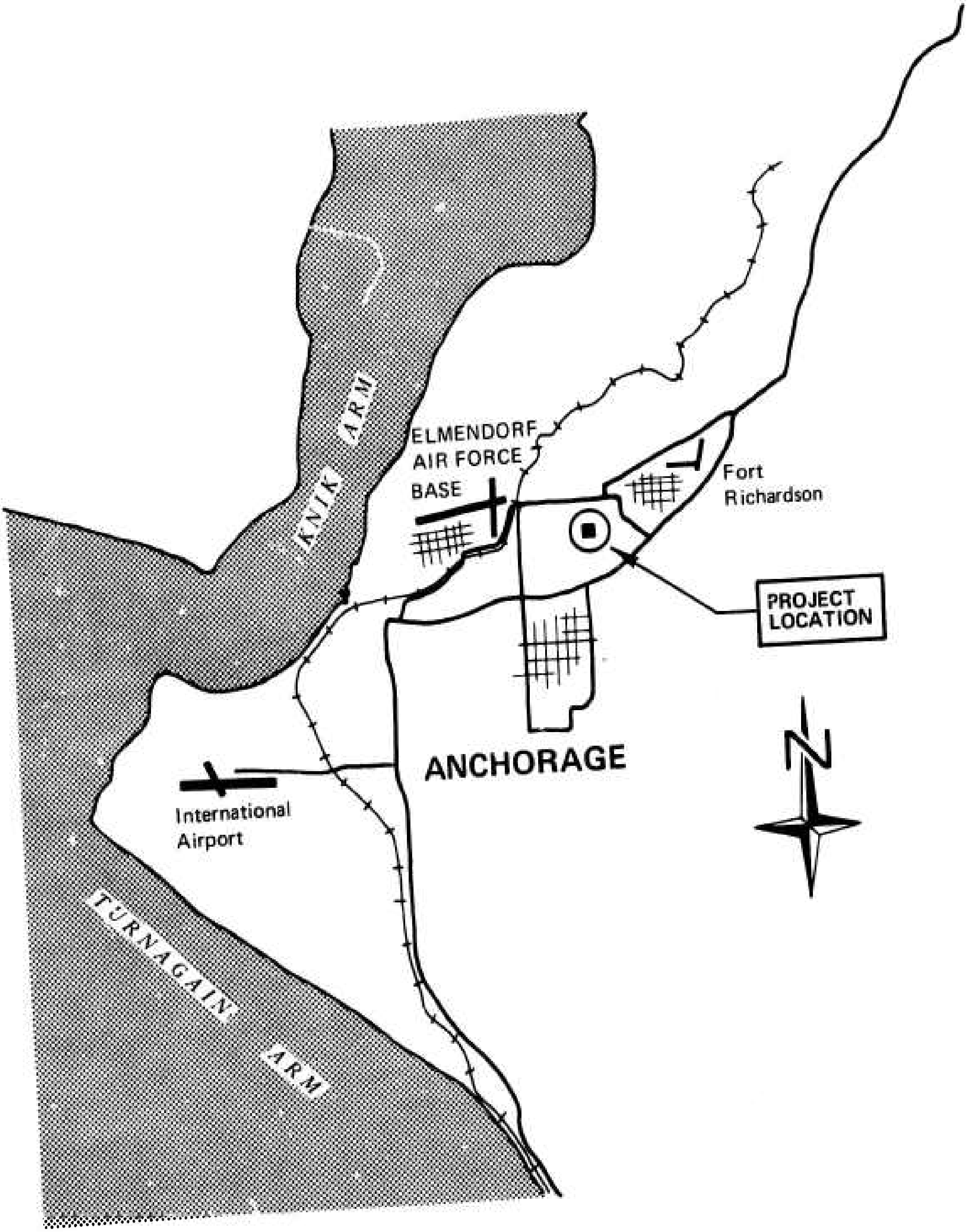


Figure 3-5 Alaska Monitor Station Locality

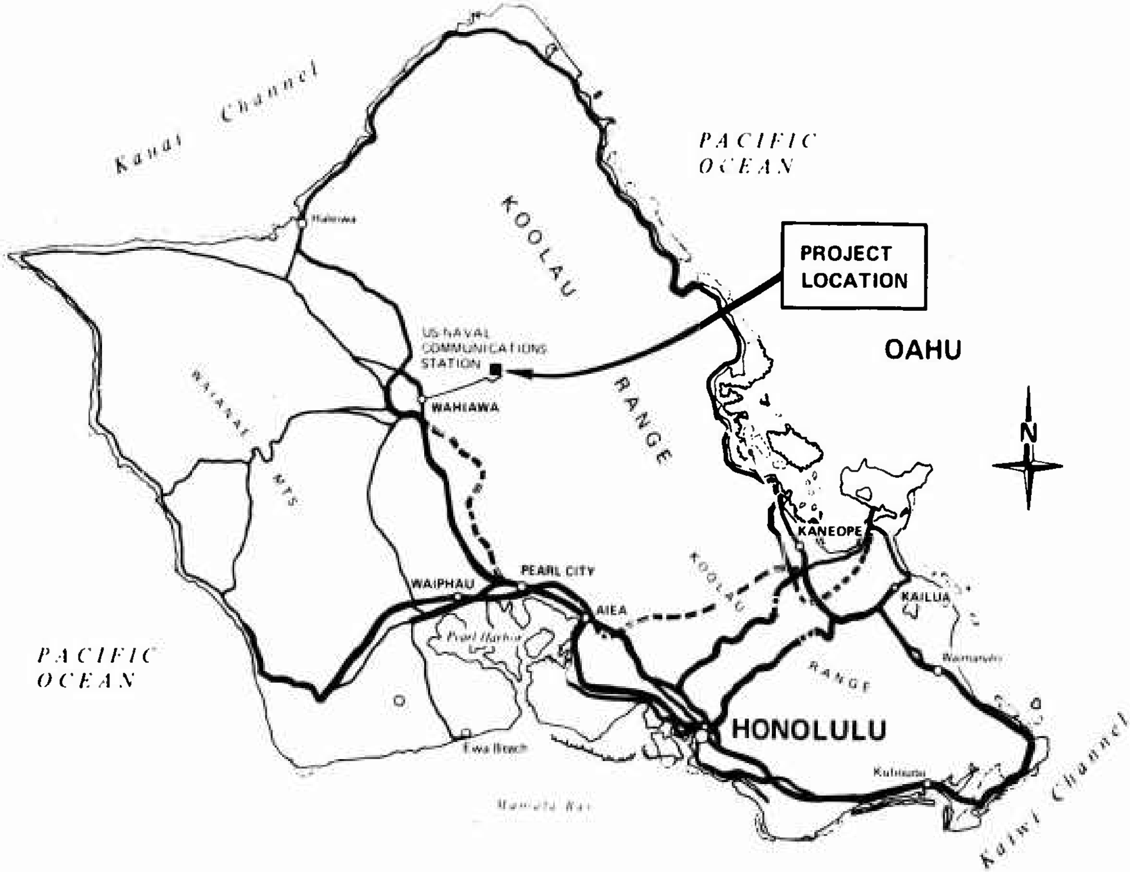


Figure 3-6 Hawaii Monitor Station Locality

TABLE 3-1
ALLOCATION OF CS FUNCTIONAL REQUIREMENTS TO THE MONITOR STATION

FUNCTION	Master Control Station			Upload Station			Monitor Station			Tele Com
	HARDWARE CI NO. 237273	SOFTWARE CPCI NO. 237309	PERSONNEL	HARDWARE CI NO. 237277	SOFTWARE CPCI NO. 237313	PERSONNEL	HARDWARE CI NO. 237275	SOFTWARE CPCI NO. 237311	PERSONNEL	CI NO. 237279
Control Segment Operations										
• Segment Initialization and Recovery		X	X			X				
• System Scheduling		X	X							
• Communications Function		X	X		X			X		X
• Display and Control Function	X	X		X	X		X	X		
• Status Monitoring Function	X	X	X	X	X	X	X	X		
Navigation Data Collection										
• System Calibration Data		X								
• Space Vehicle Tracking Data				X	X		X	X		
• System Time Standard	X	X								
• Space Vehicle Health and Status Data		X								
• Space Vehicle Access Key		X								
Navigation Data Processing										
• Tracking Data Preprocessing		X								
• Reference Ephemeris Generation		X								
• SV Ephemeris Prediction		X								
• SV Clock Prediction		X								
• Almanac Data Generation		X								
• Upload Message Generation		X								
Space Vehicle Navigation Subsystem Control										
• Navigation Upload Control		X	X		X	X				
• Upload Message Validation		X			X					
• Upload Message Transmission				X	X					
• Upload Verification and Retry				X	X					
System Test/Calibration/Maintenance										
• Control Segment Calibration				X		X	X		X	
• Ionospheric Data Collection		X								
• Navigation Performance Evaluation		X			X			X		
• Space Vehicle Signal Quality Monitoring				X	X					
• Support Software Development	X	X								
• Segment Readiness Testing	X	X		X	X		X	X		
• Segment Evaluation Testing	X	X	X	X	X		X	X		
• Logistics Support			X							

calibrating and reporting its internal biases. Each of these functional requirements is examined in detail below followed by a recap of the MS interface and availability requirements.

3.3.1.1 Space Vehicle Tracking Data Collection. The prime function of the MS is to collect SV tracking data by simultaneously receiving the L-band navigation signals from as many as four SVs. The MS will, utilizing the pseudorandom codes modulated on these signals, make pseudorange and pseudorange-rate measurements to the SVs. These measurements are to contain uncorrelated errors not exceeding 5 ft (one sigma) and 0.5 ft/sec (one sigma), respectively. These measurements will be made to each SV every 15 seconds and time-tagged with an accuracy of ±100 microseconds (relative to the MCS system time reference). The MS will also demodulate navigation data from the SV signal and will format and store this data, together with the pseudorange and pseudorange-rate measurement and time-tags, for periodic forwarding to the MCS.

- Meteorological Data - The MS will supplement its tracking data by measuring its local outside air temperature, relative humidity and barometric pressure. These meteorological parameters will be monitored continuously with the following accuracies:

Temperature	-35°F to +120°F, ±0.5°F
Relative Humidity	0% to 100%, ±3%, 32°F to 120°F 10% to 100%, ±6%, -35°F to 32°F
Barometric Pressure	700 mb to 1565 mb, ±10 mb

  The MS processor will sample and digitize the outputs of the meteorological sensors and will format and store the resulting data, together with the space vehicle tracking data, for periodic forwarding to the MCS.

- Ionospheric correction data. The MS will also collect the data required to correct the ionospheric effects by making pseudorange measurements derived from navigation signals received on two L-band carriers, at widely-separated frequencies, L1 and L2. The MS will alternately collect tracking data from L1 and L2 signals and will format and store this data together with an "L1 or L2" indicator, time of observation and satellite position.

3.3.1.2 Operator Controls and Displays. The MS is to operate unattended and, therefore, will have no full-time operator. However, operator control/display capability, in the form of a hard copy printer and keyboard entry device, will be provided to support periodic hardware and software maintenance.

3.3.1.3 Status Monitoring. The MS will monitor the status of its internal hardware and software using built-in test equipment and

hardware/software status data (eg, GO/NO-GO flags for its major LRUs/chassis) into the tracking/calibration data messages forwarded to the MCS.

3.3.1.4 System Performance Monitoring. Whenever four satellites are simultaneously visible, the MS software will process the SV tracking and system calibration data to compute a position "fix" (latitude, longitude, altitude and clock bias). The fix data will be compared with the known coordinates of the MS to derive a measure of overall GPS performance.

3.3.1.5 System Readiness Tests. The MS will, in its fully operational configuration, utilize a built-in test capability and software diagnostic routines to verify its mission support/operational readiness. The MS should be capable of providing a "station GO/NO-GO" indication within five minutes following a request from the MCS for readiness verification.

3.3.1.6 Bias Calibration. The MS must periodically measure, record and forward to the MCS all station biases which affect the accuracy of the tracking data it collects. The MS will utilize a combination of built in and maintenance test equipment to measure such parameters as delays through RF cables and amplifiers, in order to establish the precise location of the point in space that represents the true location of the MS.

3.3.1.7 Interface Requirements. To acquire tracking data the MS must establish, with the space vehicles, the interface described previously in paragraph 2.2.2. Reviewing the characteristics of this interface it is most important to note that the expected power level at the MS Antenna can be as low as -130 dBm.

Considering the MS interface with the MCS it is most important to not the requirement for RS-232-compatibility between the MS and the telecommunications network.

3.3.1.8 Availability Requirements. Referring, in Section 2, to Table 2-3, it is found that MS equipment should be sufficiently reliable to support a mean-time-between failures (MTBF) assessment of 200 hours. The equipment maintainability should support a mean-time-to-repair (MTTR) of 17.39 hours.

3.3.2 Interpretation of Requirements.

Most of the requirements stated above are quite direct. For example, it's clear that the MS, being unattended, will require extensive build-in test (BIT) capability to support the readiness and performance test requirements. Moreover, the BIT capability must support remote (ie, from the MCS) troubleshooting in order that, in case of an MS equipment failure, the MCS can dispatch the proper replacements and assistance to the MS in a manner that is consistent with the MTTR requirements. Other requirements, by themselves, are not so direct. The significance of the minimum received power level

of the L-band signals; ie, -136 dBm; becomes clear when associated with the carrier-to-noise density (C/No) ratio required to achieve the ranging accuracy specified in paragraph 3.3.1.1. Ranging error analyses, as presented in part II, Volume A of this report, show that to obtain sufficiently accurate range samples requires a C/No of 35 dB-Hz or greater. This C/No requirement coupled with a -136 dBm power level produces a derived-requirement for a receiver noise density of no greater than -171 dBm/Hz which, in turn, can be converted to a requirement for a 5 dB (or less) noise figure, referenced to the MS antenna output.

3.3.3 Monitor Station Configuration

A block diagram of the MS appears in Figure 3-7. In this figure eight major components are identified, viz:

a. Antenna-preamp package

b. L-band receiver

c. MS processor

d. MS software resident in processor

e. built-in test equipment

f. Meteorological Monitoring equipment

g. Alarm system

h. teletypwriter

These components are addressed individually below.

3.3.3.1 Antenna-Preamp Package.

Performance Requirements

The L-band receivers at the Monitor Stations will be located up to 100 feet from the receiving antennas. If the receivers were to be simply connected to the antennas through a length of coaxial cable, the resulting signal loss and noise figure degradation, regardless of the quality of the cable, would be intolerable in view of the receiver C/No requirements. Therefore, an active preamplifier is required at the antenna to overcome the effects of cable loss. This preamp will be a wide bandwidth unit -- 1.2 GHz to 1.6 GHz -- and it will have sufficient gain and a sufficiently low noise figure to satisfy the requirement for an overall receiver noise figure, referenced to the input of the preamp, of 5 dB or less.

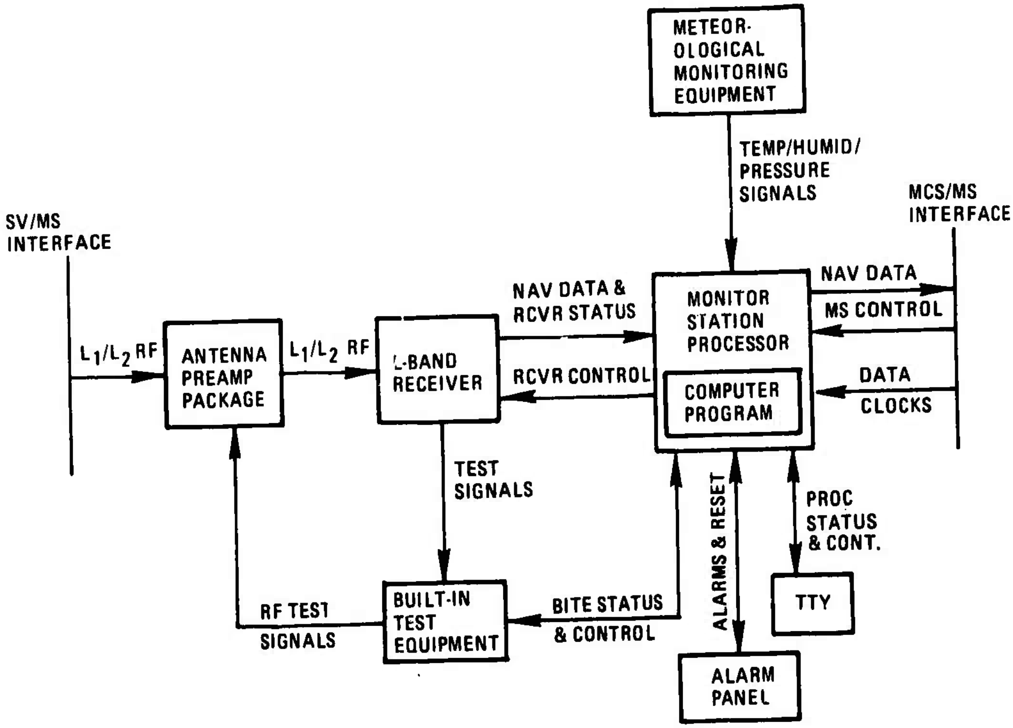


Figure 3-7 Monitor Station Block Diagram

Also, in support of the receiver C/No requirements, the antenna must possess certain specific characteristics. It must be wideband -- again, 1.2 GHz to 1.6 GHz -- and it must provide at least hemispherical coverage, ie, uniform gain -- 0 dBi -- for all elevation angles above 5 degrees. When the added signal losses that occur at low elevation angles (due to increased slant range to the space vehicles, increased atmospheric attenuation, etc.) are considered, one concludes that the ideal antenna should have more (and positive) gain at low elevation angles (but not below 5 degrees to avoid multipath signal reception) than at zenith. A pattern, which accounts for the increase in loss as elevation angles decrease, is shown in Figure 3-8. [Unfortunately, to provide the ideal pattern would require an antenna possessing nearly 100 percent efficiency and such an antenna is a practical impossibility. Investigations of antennas approaching the required efficiency are, of course, underway but the baseline configuration reflects a conservative approach wherein standard, off-tne-shelf antennas are employed.]

The other characteristics that must be exhibited by the antenna are right-hand circular polarization, low axial ratio, low VSWR and a physical design that will withstand the rigors of both tropical and arctic environments.

Performance Characteristics

The L-band antenna will be a hemispherical omnidirectional, conical spiral antenna. Its form is that of a cone, with its radiating elements wrapped about the cone and encapsulated in isocyanate foam and covered by a low-loss dielectric radome. The antenna is right-hand circularly polarized with a VSWR of 1.35:1, typical, at 50 ohms impedance. The operational frequency range of the antenna will be from 1.2 GHz to 1.6 GHz; adequately enclosing the two navigational frequencies. Typically this type of antenna will exhibit patterns similar to those shown in Figures 3-9 and 3-10.

The pre-amplifier at the antenna is a wideband, transistorized amplifier. It exhibits a gain of 32 dB with a noise figure of about minus 4.5 dB over the applicable frequency range. Using silicon transistors and encapsulated circuitry throughout, the preamplifier will provide a frequency pass band from 1 GHz to 2 GHz with maximum VSWR's of 2.0:1 both in and out at 50 ohms impedance.

The coaxial cable utilized to carry the L1 and L2 navigational signals from the pre-amplifier to the power divider and receiver within the monitor station, exhibits a cut-off frequency of 10.0 GHz and has an impedance of 50 ohms. The nominal loss characteristics are such that within the operational frequency range, only 3.0 to 4.5 decibels are lost per 100 feet of cable. The cable is of 1/2 inch diameter with a polyethylene (foam) dielectric to provide.

Since all the satellites will be transmitting on the same two frequencies (L1 and L2), more receivers must eventually have access to the received L1 and L2 signals as more satellites are incorporated

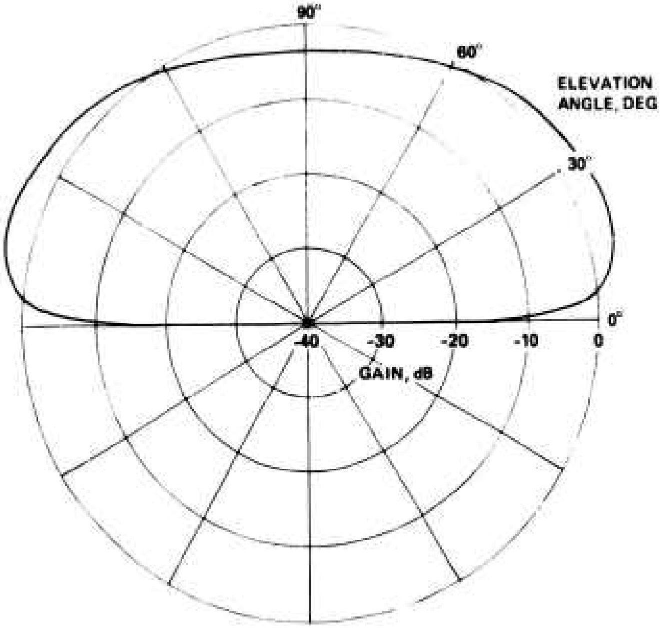


Figure 3-8 Ideal Antenna Pattern

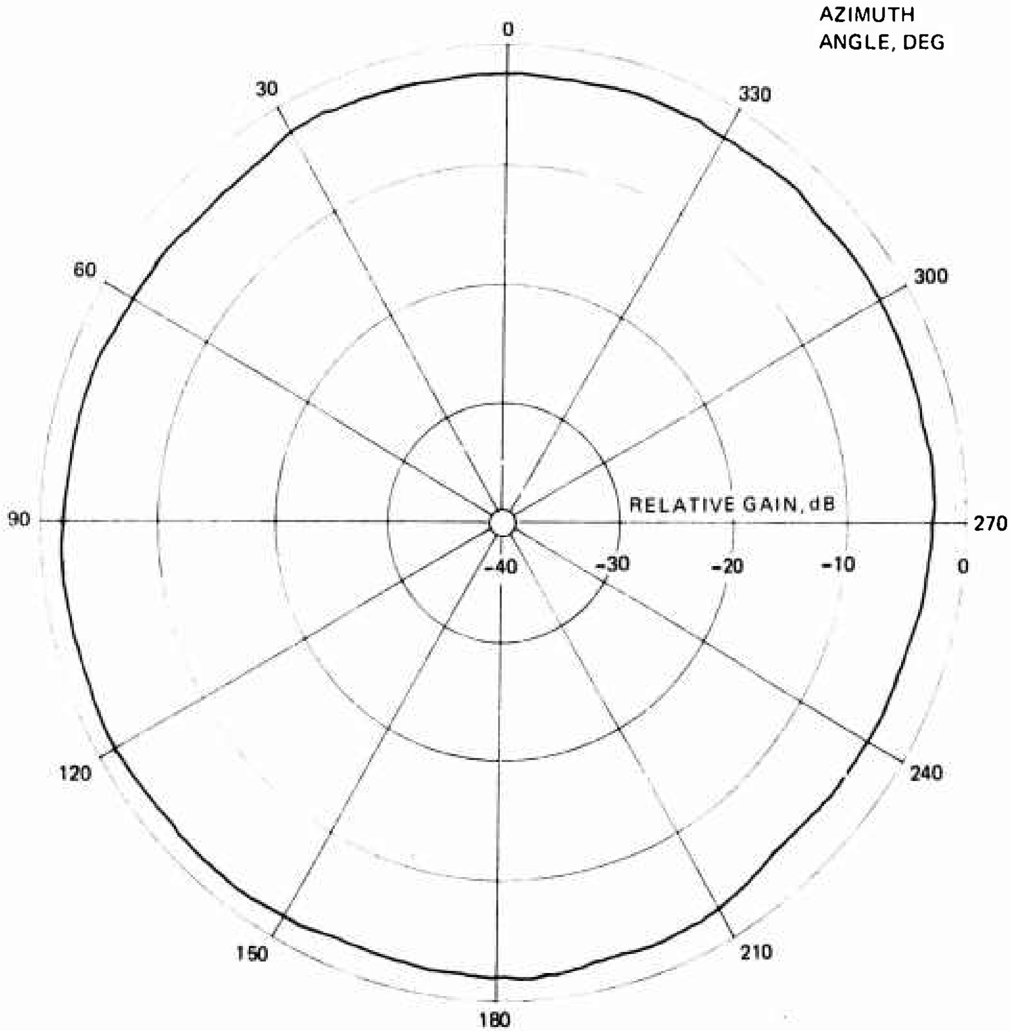


Figure 3-9 Plan View of Antenna Pattern (45° Elevation Cut)

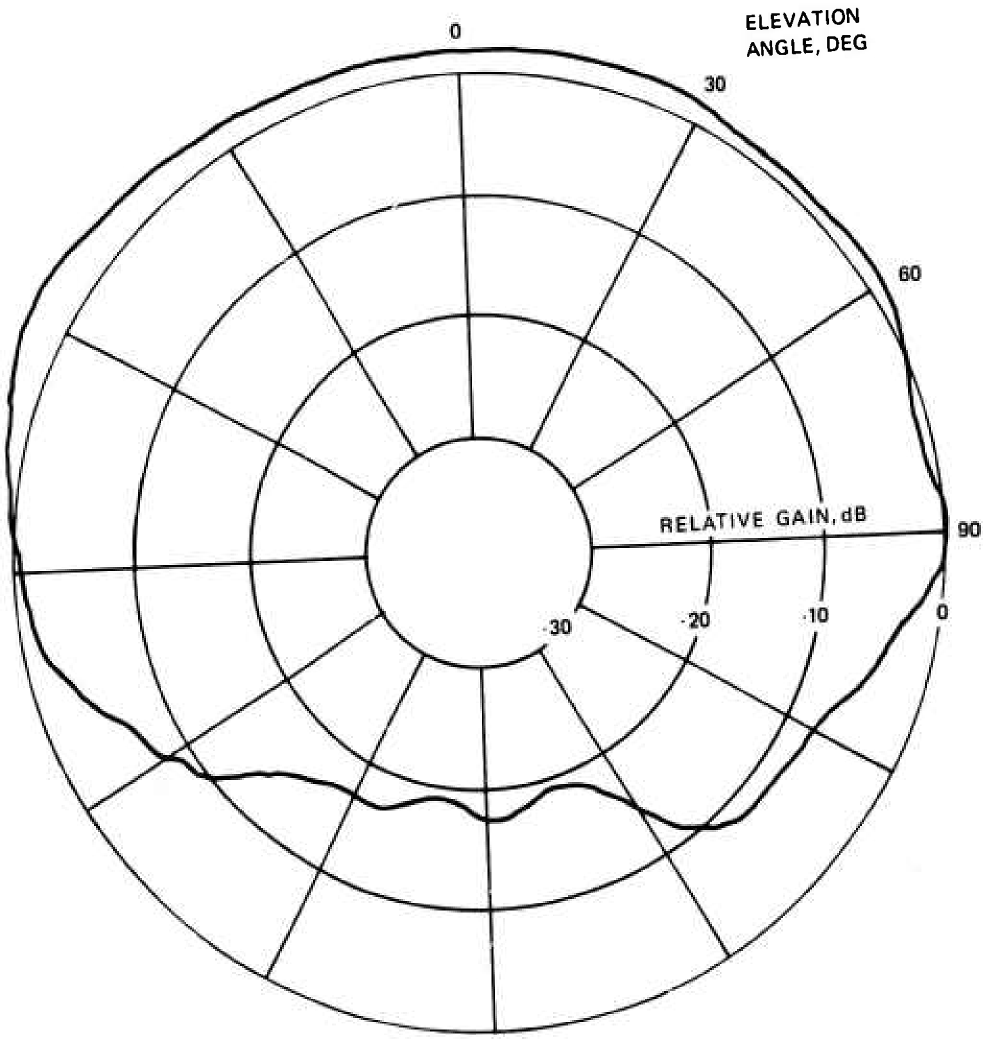


Figure 3-10 Side View of Antenna Pattern

into the system. For this reason a power divider is provided immediately prior to the signals reaching the receiver(s). This power divider is a 4-way, in-phase power divider with a low insertion loss of 0.6 dB. Its design incorporates high isolation between output ports as well as VSWR's of 1.3:1 at both input and output. A frequency response from 1.0 to 2.0 GHz along with good amplitude and phase balancing of the power division, provide for acceptable operational characteristics.

The interconnection of the antenna, preamp, cable and power divider is shown in Figure 3-11. Using the gains, losses and noise figures shown in the figure, one can compute the receiving system noise temperature (excluding the antenna temperature) to be 555°K. The noise temperature converted to noise figure is 4.62 dB which is better than the requirement of 5 dB.

Configuration

Figure 3-12 shows a typical conical-spiral L-band antenna in its protective radome. The phase shifting network required by the antenna for its proper operation and the L-band preamp are housed within the cone. Power (28 Vdc, 100 mA, nominal) for the preamp will be provided by the receiver and carried by the coax cable -- the power will be applied to and removed from the cable through low-pass filters. The power divider will be located in the receiver rack behind the RF interface panel.

3.3.3.2 L-Band Receiver

Performance/Design Requirements

The design of the MS L-band receiver will nearly duplicate that of a four-channel ("Class A") user navigation receiver. The user receiver design will, however, require some modification to accommodate the unique interfaces presented by the other MS equipment. The interface with the MS processor is the same as in the user environment, with the exception that data time-tags/interrupts are required to identify the pseudo-range/range-rate data samples for the processor at the MCS. Also, the MS built-in test equipment requires access to a replica code generator, from which test signals will be derived, and to receiver AGC voltage and several VCO outputs for receiver performance evaluation.

Performance/Design Characteristics

Figure 3-13 is a block diagram of the MS L-band receiver. The input signal to the receiver is from the power divider described in the preceding paragraph. The input signal is the composite of L1 and L2 signals from up to four space vehicles. The task of the receiver is to "sort-out" these eight signals, make pseudorange and pseudorange-rate measurements and extract navigation data.

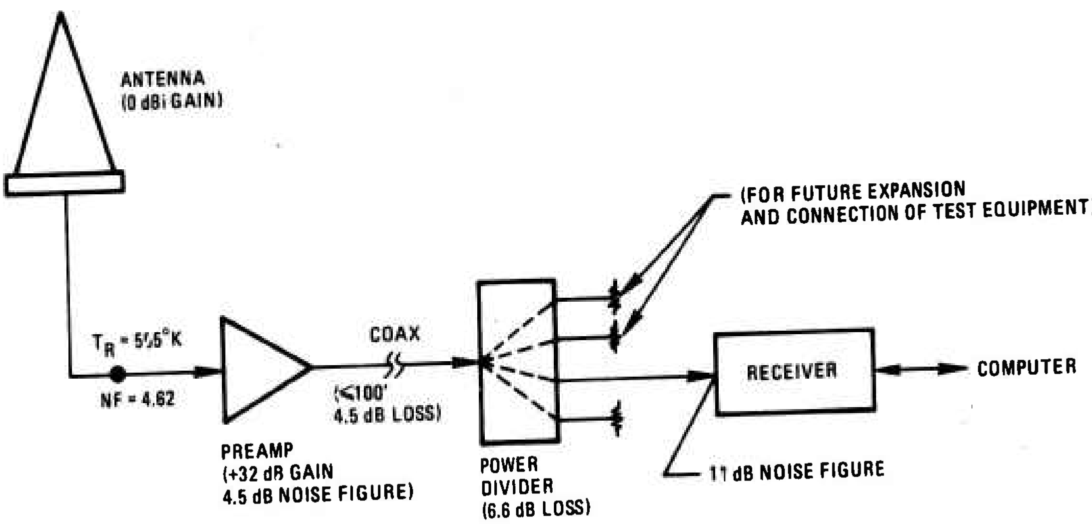


Figure 3-11 Block Diagram of Antenna Equipment

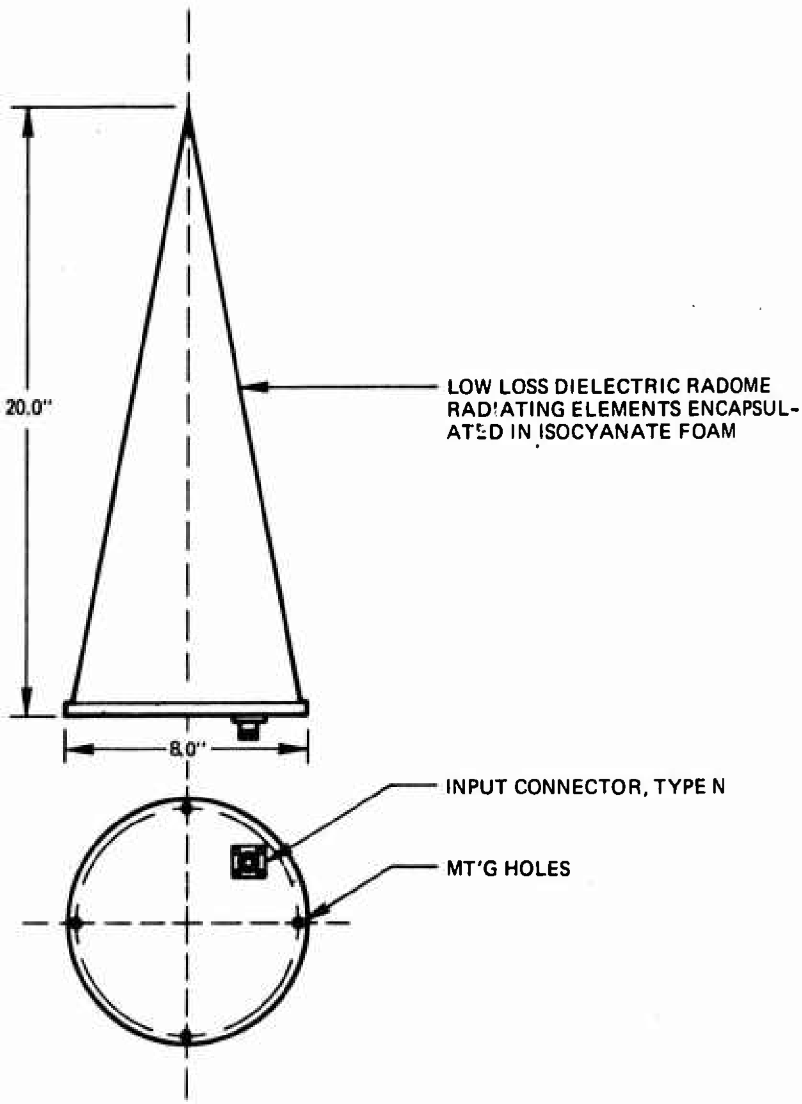


Figure 3-12 Physical Appearance of Typical L-Band Antenna

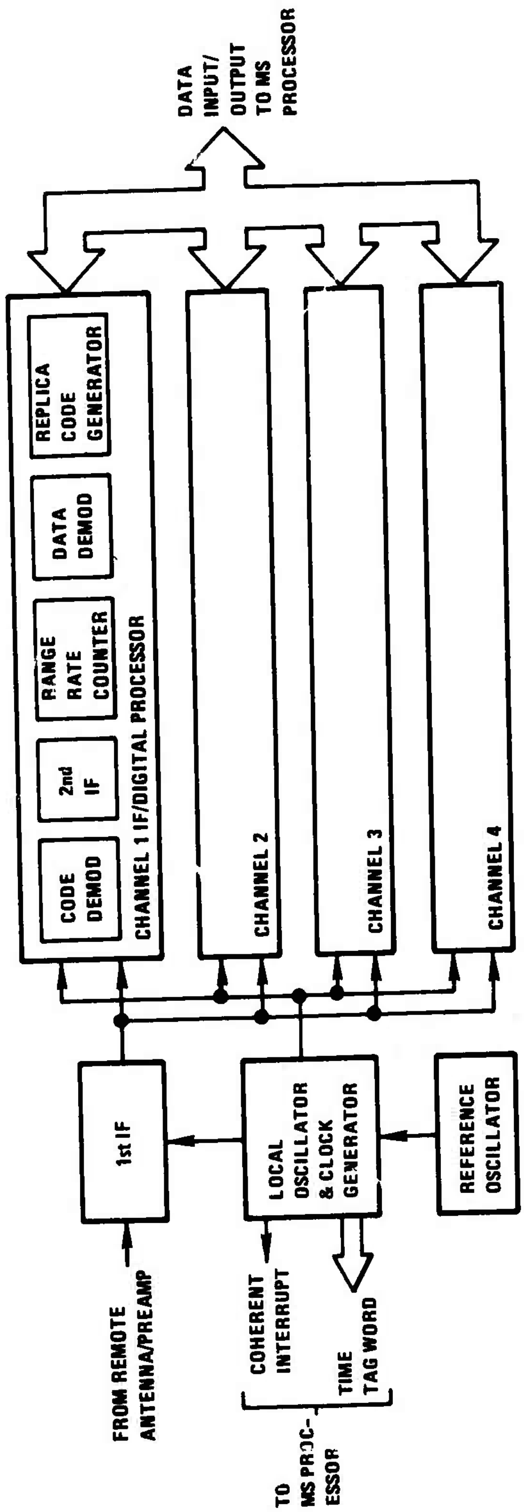


Figure 3-13 L-Band Receiver Block Diagram (4-Channel Configuration)

The reader is referred to the system analysis report for the user segment, Part I, Volume B, for a detailed discussion of receiver operation.

By changing the local oscillator frequencies the receiver provides to its IF stages, the receiver can selectively process either L1 or L2 signals. To distinguish one space vehicle signal from another, unique pseudorandom codes are modulated onto the L1 and L2 carriers broadcast by the vehicles. By creating replicas of these codes and correlating them with the received codes, the receiver can select signals from specific vehicles -- each channel of the four channel receiver creates a replica code for a different vehicle and thereby processes signals only from that vehicle.

The data delivered by the receiver to the monitor station processor (MP) is shown in Table 3-2. Referring to the table, the MP assembles the three range words -- coarse, medium and fine -- into a single pseudorange word. Likewise the coarse and fine velocity are assembled into a single pseudorange-rate word. These two words plus the satellite ID, the time-tag and the "L1 or L2" flag are then assembled into a measurement set which is stored and subsequently transferred to the MCS. In addition to measurement data the receiver also transfers navigation data, demodulated from the L-band signals, across the receiver/processor interface in 32 bit bytes. More details of this data acquisition process are provided in the description of MS software presented in paragraph 3.3.4.

The MP, in turn, "controls" the receiver by providing satellite selection commands which establish the formats of the replica codes to be generated within each receiver channel. In addition, the MP provides computed estimates of range and doppler to each channel to assist the receiver in rapidly acquiring the vehicles' codes and carriers.

Referring once again to Table 3-2, one notes a reference to a "Z-number" time-tag. Typically, the time-tag and its associated interrupt would be provided by a fifth P-code replica generator located in the clock generator module of the receiver. This code generator would be dedicated to generating data time-tags and interrupts and test signals for the MS built-in test equipment. The configuration of a typical P-code generator, conforming to GPS code-generation standards, is shown in Figure 3-14.

A typical data transfer sequence, using the 1.5 sec interrupt and Z-number time-tag, is shown in Figure 3-15. The sequence starts with the transfer of pseudo-range/range-rate measurement data taken with the receiver operating at L2 (the "L2-flag" is set in the transferred data). Then, for the next four interrupts, bytes of P or C/A data are transferred (a "P or C/A" flag indicates the type of data). The P or C/A data is followed by a transfer of pseudo-range/range-rate measurement data taken at L1. Next, four more bytes of P or C/A data are transferred followed by an L2 measurement set, and so on. After

TABLE 3-2

L-BAND RECEIVER TO MONITOR PROCESSOR INTERFACE

Data/Signal	No. of Bits	Resolution	Sample Period, Sec	Comments
Coarse Range	22	100 ft (P) 1000 ft (C)	15	4 "words", one per channel
Medium Range	2 (P) 6 (C)	25 ft 25 ft	15	4 "words", one per channel
Fine Range	8	0.635 ft	15	4 "words", one per channel
Coarse Velocity	14	4.92 fps	15	4 "words", one per channel
Fine Velocity	9	0.0492 fps	15	4 "words", one per channel
Satellite ID	9	--	15	4 "words", one per channel
P or C/A flag	1	--	15	4 "words", one per channel
"Lock status" flags	2	--	15	4 "words", one per channel
Time-tag (Z No.)	19	1.5 sec	15	1 "word" only
Interrupt	--	--	1.5	1 "word" only
"L1 or L2" flag	1	--	1.5	1 bit only
Data Ready Acknowledge	1	--	--	In response to MP data ready

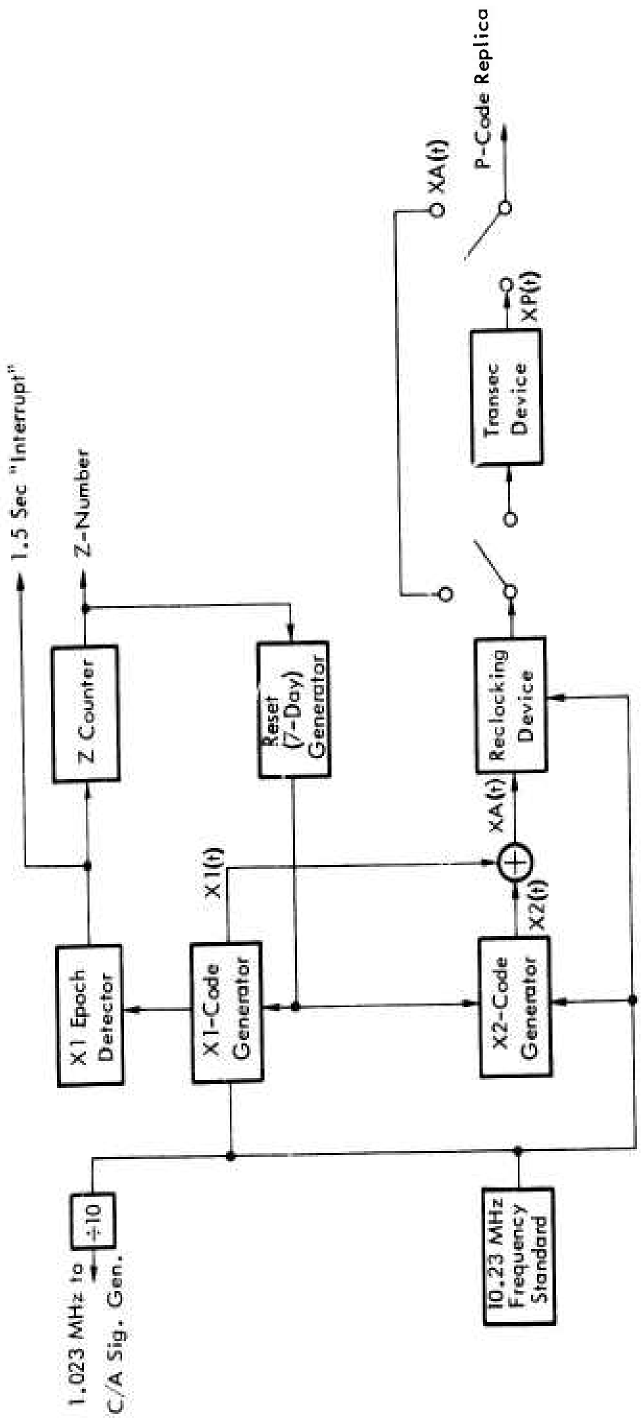


Figure 3-14 P-Code Generator Block Diagram

TIME	TIME-TAG	DATA TRANSFER
t = 0	Z-NUMBER = N	L2 DATA
		BYTE 1 (P OR C/A DATA)
		2
		3
		4
		L1 DATA
		BYTE 5
		6
		7
		8
t = 15 SEC	Z = N + 10	L2 DATA
		BYTE 9
		10
		11
		12
		L1 DATA
		BYTE 13
		14
		15
		16
t = 30 SEC	Z = N + 20	L2 DATA
		BYTE 17
		18
		19
		20
		L1 DATA
		BYTE 21
		22
		23
		24
t = 45 SEC	Z = N + 30	L2 DATA
		BYTE 25
		26
		27
		28
		L1 DATA
		BYTE 29
		30
		31
		32
t = 60 SEC	Z = N + 40	L2 DATA

Figure 3-15 Typical Tracking Data Transfer Sequence

40 interrupts -- 60 seconds -- a complete frame of P or C/A data will have been transferred along with five L2 and four L1 measurement sets.

The processing algorithms used at the MCS to generate satellite ephemerides and clock corrections provide, in addition, a precise measure of the drift of the MS clocks (frequency standards) as one of their outputs. Therefore, low-drift clocks would appear unnecessary insofar as any clock drift, large or small, would be "computed out" and, accordingly, would not affect the quality of the upload data computed from the MS-supplied navigation/tracking data. However, some of the navigation data processing algorithms being considered for GPS service employ relatively long "averaging times" over which the MS clocks would be required to drift no more than one nanosecond. As these averaging times increase the feasibility of using crystal standards diminishes. The baseline MS configuration is founded on the use of the crystal standards normally provided with the user navigation receivers. But, it is recognized that external atomic standards, most likely Rubidium, may be required at the MS.

3.3.3.3 Monitor Station Processor

Performance Requirements

The principal function of the monitor station processor (MP) is to host the MS software described in paragraph 3.3.4 and to present compatible input/output ports to other MS equipment, such as the meteorological monitoring and built-in test equipment, and to the terminal equipment of the telecommunications network.

Performance Characteristics

To support the MS software the MP will be a general-purpose, digital, scientific mini-computer with the capability of executing the instruction mix presented by the MS software at a minimum rate of 48,000 instructions per second. In addition, the MP will have a high-speed random access memory with a capacity of at least 36,000 16-bit words. To satisfy slower-speed (ie, 50 millisecond access time, as opposed to a one microsecond access time for the highspeed memory) mass storage requirements the MP will incorporate a 0.5 megaword disc storage unit.

The central processing unit will feature:

a. hardware index registers, arithmetic registers and general-purpose registers all capable of supporting 16-bit operations.

b. a conventional instruction set including load-and-store, arithmetic, logical, shift, data transfer and test-and-branch instructions.

c. double-precision hardware that will provide at least 24 bits of precision in floating-point operations

d. A capability to address all of the random access memory and to direct-address at least 16,000 words.

A block diagram of the MP appears as Figure 3-16.

Regarding interfaces, the MP will provide a high-level analog-to-digital converter and a multiplexer to service the three analog signals from the meteorological monitoring equipment. Twenty-three control lines and 45 status/indicator lines will be reserved for BITE input/output. A half-duplex synchronous, RS232C-compatible 2000 bps modem interface plus as auto-dial interface will be incorporated to service the telecommunications equipment.

Since the MS is to operate unattended, provisions for power loss (or cut-of-tolerance conditions) will also be incorporated in the MP. That is, sensing of an emminent power loss will initiate the storage of key registers and the random access and disc memories will be protected from alteration. When power is restored they will be capable, using a bootstrap program stored in a non-volatile (read-only) memory, to automatically restart.

3.3.3.4 Built-in Test Equipment. The built-in test equipment (BITE) provided at the MS will comprise a set of three multiposition coaxial switches, a biphase modulator, frequency multipliers, a digital voltmeter (DVM) and a frequency counter; all capable of operating under MS processor control. The L-band receiver will provide the BITE with a P-code replica and a sample of the 1st IF local oscillator output. The BITE will amplify the LO signal, biphase modulate it with the P-code replica and translate it to L-band to serve as the spread-spectrum RF test signal output of the BITE.

A three position coaxial switch will, under MS processor control, route the RF test signal through fixed attenuators to directional couplers at 1) the input to the RF preamp, 2) the output of the preamp, and 3) the input to the receiver, following the power divider. The attenuators will be adjusted such that the test signal levels will be appropriate for their point of application so that the signal appearing at the receiver input will have the same level regardless of the test signal path -- if the preamp, etc. are operating properly.

The MS processor will assist the four channels of the receiver in acquiring the BITE signal by providing control words to the receiver which will effectively cause all the code replica generators within the receiver to be slaved to the BITE dedicated generator.

Then, as a result of switching the input signal to the various input points, AGC voltages will be developed in the receiver, which will be representative of the input power level applied to the receiver. The AGC voltage developed by each of the four receiver channels will be

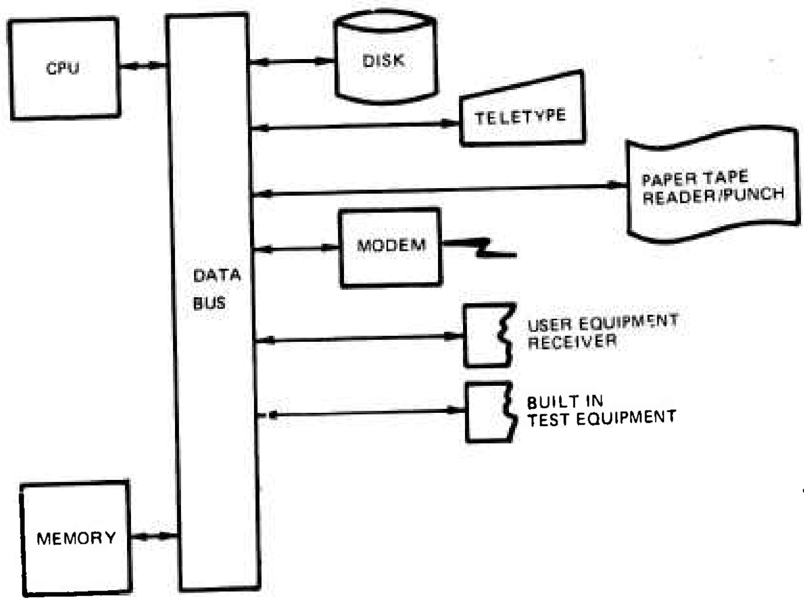


Figure 3-16 Monitor Station Processor Equipment Configuration

scanned by a multi-point switch, under control of the MS processor. This switch is identified as the digital voltmeter (DVM) input selector.

This DVM input selector switch also routes other test point signals, DC and AC, to the DVM, as ordered by the MS processor. As the processor selects various signals sources as inputs to the DVM, it programs the DVM to measure DC or AC volts, corresponding to the requirements of the particular test point selected. The output of the DVM is in 1-2-4-8 BCD code, which is input to the MS processor. Other inputs to the DVM selector switch are the data lines between the receiver and the processor, the data side of the communications modem, and the outputs of crystal detectors on the LO lines.

A second input selector switch serves to provide inputs to a frequency counter. The signals selected for frequency measurement are the VCO's 40 MHz outputs, the 10- 15- and 40- MHz reference frequencies and the first LO signal before multiplication. THe counter is automatic, so that it provides a BCD output number for any signal within the counter's frequency range and above its threshold.

3.3.3.5 Meteorological Monitoring Equipment. The temperature, pressure and relative humidity of the atmosphere are measured to provide data for calculations which will eliminate the errors due to delays inherent in the MS pseudorange measurements. The goal is to reduce all atmospheric error effects to less than one half foot and thereby eliminate them from the error budget. Specifically, the measurements to be made are as follows:

Temperature	-35 to 120 deg F ± 2 deg
Pressure	700 to 1065 mb ±10
Relative Humidity	0 to 100% ±2%

Relative humidity can be measured several ways -- directly or by measuring dewpoint temperature. However, obtaining relative humidity by measuring dewpoint has two serious drawbacks: measuring depressed dewpoint to obtain ±2% accuracy requires ±0.4 deg F temperature measurement accuracy (not obtainable) and periodic sensor sleeve retreatment (once a year) of the lithium chloride of the dewpoint sensor. In addition, a contaminated atmosphere could require more frequent retreatments of the dewpoint sensor than once a year. Instead a relative humidity meter which measures RH 0 to 100% ±2% from -40 deg to ±175 deg F was chosen. The RH unit measures the capacity change of a polymer thin film capacitor which is proportional to RH. Temperature compensation is not required.

The temperature probe together with the RH sensor are mounted in a motor aspirated radiation shield located at the top of a 30' (recommended Weather Bureau standard) tower. The pressure sensor and all electronics are mounted in the monitor station racks.

3.3.3.6 Alarm System. The principal function of the MS alarm system is to alert host facility personnel to a malfunction of the MS equipment so that they can either provide cursory troubleshooting and/or notify the MCS. The alarm system comprises two items, an alarm controller and an alarm panel.

Alarm Controller

The alarm controller will provide warning of malfunctions in the MS equipment. The controller will contain a timer, which must be periodically reset by the MS processor. Failure of the MS processor to reset the timer before the selected interval elapses will cause the alarm to sound and flash. The alarm controller timer will inhibit the alarm signals for 5 minutes following a reset. At 4 minutes and 30 seconds after reset the alarm system will raise an interrupt line, which instructs the computer to perform a status check of all the MS equipments. If the status check is "good" the computer will send a reset signal to the alarm, which will inhibit the alarm signals for 5 more minutes, until the next equipment check has been ordered and the reset either sent, or not sent, to the alarm controller. The alarm controller will energize the lines leading to the alarm signal panel in the host facility. The alarm controller will be located in the MS racks.

Alarm Panel

The alarm panel will be installed in the host facility. The alarm panel will be a standard 19-inch rack panel, 3 1/2 inches high. The panel will provide an audible alarm accompanied by a red light flashing 2 per second with approximately equal on- and off-times. A switch will disable the audible alarm, but the flashing light will function until the alarm system is reset at the alarm controller on the MS premises. The audible alarm disable will drop when the controller is in the maintenance mode, so that the audible alarm can not be defeated. The alarm panel will be energized by the host facility, 115-volt, 60 Hz power.

3.3.3.7 Teletypewriter. The MS will normally operate unattended, however, there are periods (eg, during bias calibrations, equipment alignment, etc.) when the MP must be addressed through a local input/output channel. Such a channel will be provided by a teletypewriter (TTY). The TTY will be an ASR-33 or equivalent standard unit providing paper tape punching and reading capability and hardcopy printout.

3.3.4 Monitor Station Software

The monitor station software resident in the MP provides for the collection of a pseudo-ranging, meteorological, and status data, computation and comparison of navigation solutions with known monitor position, and the transmission of data to the master control station. Five functions, shown in Figure 3-17, provide the necessary processing, viz:

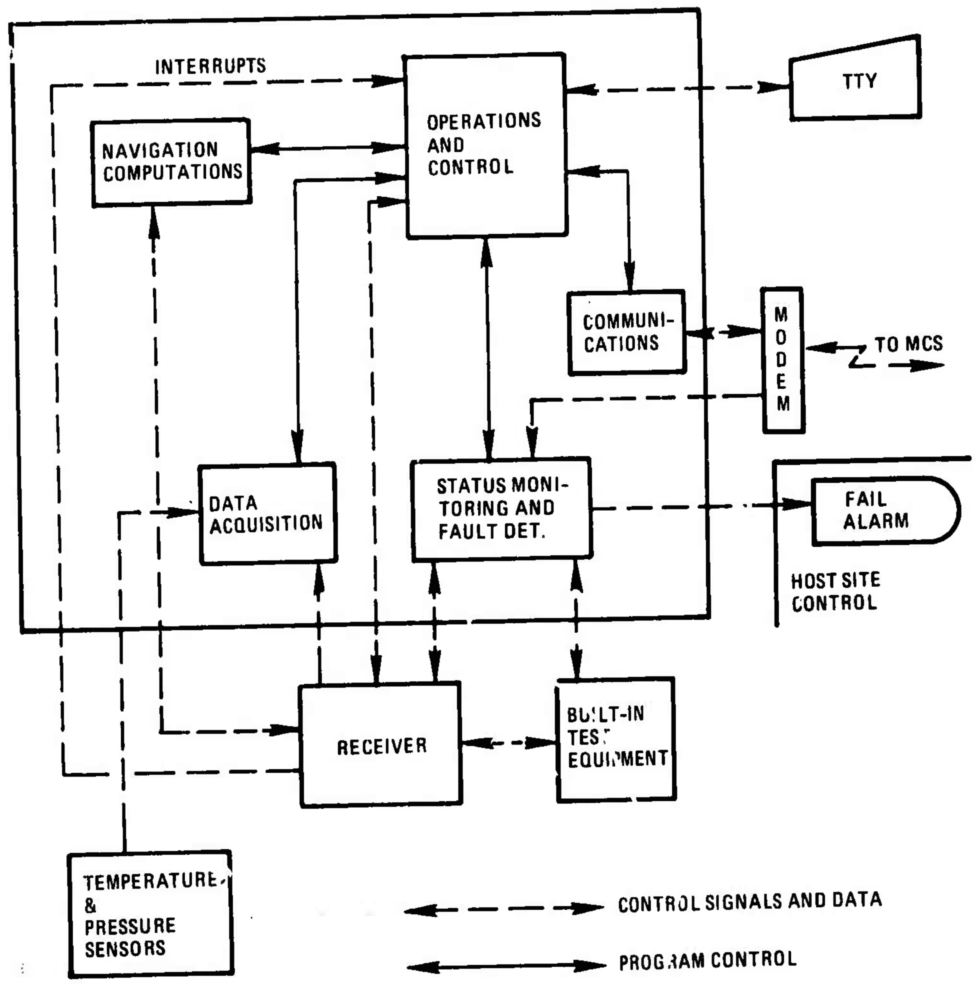


Figure 3-17 Monitor Station Software

a. Station Control

b. Data Acquisition

c. Navigation Computation

d. Status Monitoring and Fault Detection

e. Communications

The monitor station receives a basic activity schedule from the MCS. During the normal tracking mode of operation, the receiver is initialized and sequenced through normal receiver operation, including acquisition of satellite tracking signals, collection of data frames and ranging measurements, and computation of navigation solutions. Receiver interrupts provide the stimulus for periodic collection of ranging data, meteorological data, and navigation solutions. This data is stored in the data base for transmission to the MCS. The status monitoring function is executed periodically to collect monitor station status data, which is also stored in the data base.

The monitor station responds to periodic polls from the MCS, transferring accumulated tracking and status data from the data base to the master control station. Two-way communications are supported with the MCS for modification of station schedule, message interchange, and station testing. Built in Test Equipment at the monitor station provides for status monitoring and fault detection of station equipment. It may be exercised during the test mode of operation on command from the MCS or from a local TTY operator.

3.3.4.1 Station Control. This program controls the execution of monitor station software. The required activity consists of response to equipment interrupts and initiation of required programs, maintenance of station schedule and initiation of scheduled programs, support of communications with master control station, support of operator control/display interface with local TTY, and initialization and control of receiver operation.

The monitor station operates in either a tracking mode or a test mode, as determined by the station activity schedule. The activity schedule contains satellite pass data which is updated by transmission from the MCS on a weekly basis. This data is used by the control function to schedule satellite tracking and to provide acquisition and control signals at the receiver interface.

The control program provides executive control for the basic operational programs (Data Acquisition, Navigation Computation, Status Monitoring and Fault Detection, and Communications). An interrupt monitor is provided for response to equipment interrupt requests and initiation of interrupt-driven programs. During normal tracking mode operation, the following activity is accomplished:

a. Execution of Navigation Computation Programs on interrupt as specified for equivalent user set operation.

b. Execution of Data Acquisition Program on 15 sec. intervals determined by receiver interrupts.

c. Execution of Status Monitoring and Fault Detection Program as scheduled (30 sec. intervals).

d. Execution of Communications Program on interrupt request from communications equipment (hourly poll from MCS).

e. Poll of interrupt monitor and response to requests from MCS or local TTY.

f. Monitoring of software operations. An operational timeline is illustrated in Figure 3-18.

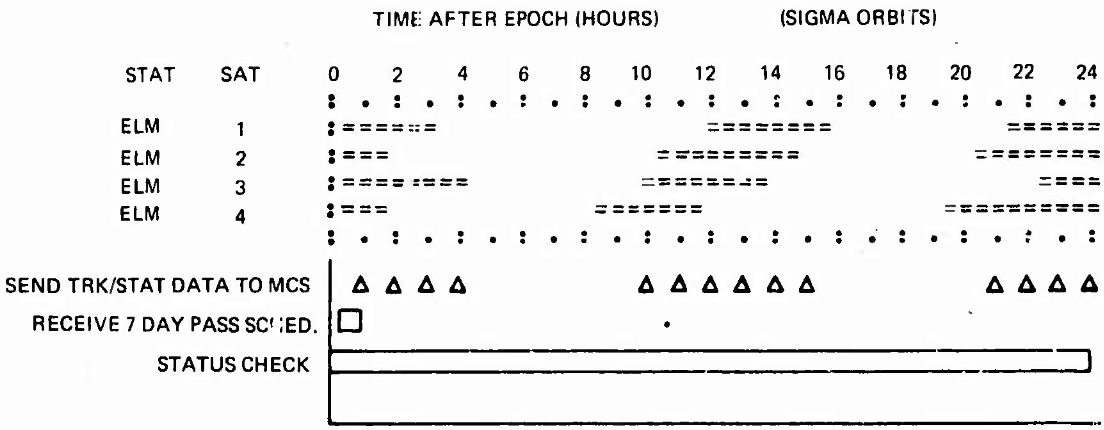
A communications monitor is provided within the control program to support the data interchange between the monitor station and the MCS. Two capabilities are included: interface with the communications program, and processing of incoming data. The communications interface specifies the locations of data to be transmitted or the areas in which incoming data is to be stored. With this information specified, the communications program can be executed without further interaction with the control program.

Incoming data from the MCS consists of schedule data, satellite pass data requests from MCS operator consoles, messages to TTY, control commands for station tests, request for transmission of accumulated tracking/status data. Data is made available to the appropriate software modules and requests for program executions are issued as required.

Test mode operations are conducted by the Status Monitoring and Fault Detection Program under command control from the MCS or local TTY. The control program supports this function by responding to requests for test mode operation, scheduling and initiating the Status Monitoring and Fault Detection Program, and processing test sequence commands through the communications monitor and a TTY monitor.

The TTY monitor provides an operator interface for test and maintenance commands, changes to station operation parameters, and message interchange between the local operator and MCS consoles.

3.3.4.2 Data Acquisition. The Data Acquisition program provides for the acquisition of data which satisfies the primary requirement for the monitor station. The program is executed on periodic receiver interrupts according to the sampling rate required for collection of tracking data. Since range measurement smoothing requires a maximum sampling interval of about 18 sec., and receiver interrupts are available at 1.5 sec. intervals, a convenient 15 sec. sampling interval is used. For each program execution, a set of tracking data



Δ ~ 3.8 MIN COMM. TIME (1500 BPS THROUGHPUT)
□ ~ 1 MIN COMM. TIME

Figure 3-18 Monitor Station Operational Timeline - Phase I (Elmendorf, Typical)

(consisting of L1 and L2 pseudorange and pseudo-range rate measurements and satellite ID) is collected for each operational receiver channel (ie, for each satellite being tracked). Additionally, the receiver Z counter is sampled to provide a time tag for the data.

Data frames received from the satellites are sampled periodically (hourly) for verification. Frame checking and comparison is performed in order to monitor effective error rates, and, if these exceed expected values, data frames from the satellite in question are saved for transmission to the MCS.

Meteorological data (consisting of barometric pressure, dry and wet bulb, temperature) are sampled on a periodic (15 min) basis from sensors provided at the monitor station. These measurements provide the necessary data for the atmospheric range corrections made at the MCS.

User position solutions computed by the navigation computation program are periodically compared with the known monitor station position and the results saved for transmission to the MCS. The data collected by the data acquisition program is arranged in data files by data type and is accumulated until a data dump is requested by the MCS. Typical data accumulation is illustrated in Figure 3-19.

3.3.4.3 Navigation Computations. Navigation Computations programs consist of routines which perform equivalent user computations, ephemeris computations, range measurement corrections, and navigation solution computations.

Satellite selection is derived from information contained in the station schedule (including satellite ID, rise time, set time, and acquisition data for each satellite).

Sequencing and control of navigation programs is provided by a executive routine within the station control program.

3.3.4.4 Status Monitoring and Fault Detection. Status monitoring is performed on a periodic basis, and station testing is performed as specified by the activity schedule or an operator request.

Status monitoring provides software and hardware checks and maintains a record of station health. Data are collected from station equipment, receiver, and station processor on at least a chassis-level basis. Identifiable units which are checked for "go" or "no-go" status are antenna/preamp, receiver, IF/Digital processor (each channel), communications modem, BITE, meteorological data sensors, station processor.

Software status checks provide an indication of software integrity by ensuring some degree of memory protection. Program areas and data areas are checked for illegal memory overwrites.

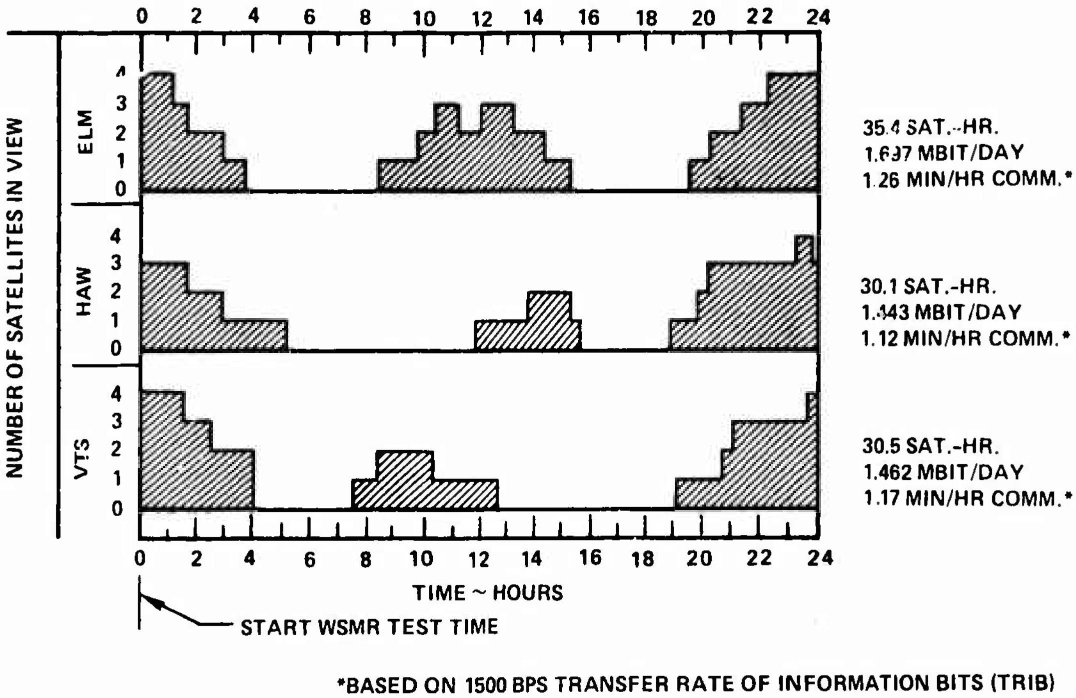


Figure 3-19 Typical Data Accumulation at the Monitor Stations

Station test programs exercise the built-in test equipment (BITE) for tests of monitor station operation. Test sequencing and control are provided by commands transmitted from the MCS or issued by the station TTY operator. The BITE generates a test signal which is injected at the receiver and appears as a satellite signal. Resulting station behavior is monitored to provide a basic test of operational units.

3.3.4.5 Communications. The communications program provides the data link between a monitor station and the MCS. Data is transferred on periodic request from the MCS. The monitor station communications equipment automatically receives dial-up requests from the MCS and issues an interrupt request to the monitor control function for execution of the communications program.

Data transmitted to the MCS consists of tracking data, vehicle and system status, navigation solution data, meteorological data, and messages for display at MCS operator consoles.

Data received from the MCS consists of station schedule information, control commands, and messages for the local TTY. A sample communications load is illustrated in Table 3-3.

The communications program is responsible for formatting and transmission of the data specified by the control program communications monitor. Likewise, it receives and validates incoming data, and stores the data in specified areas. Send/receive coordination is maintained with the MCS and data is retransmitted on detection of error.

3.3.4.6 Operating System Environment. The monitor station software operates in a vendor supplied real time operating system environment. The basic operating system capabilities assumed are a task scheduler, interrupt handler, file handler, TTY driver, and communications handler. The system also provides a high-level language compiler and assembler.

The basic interface with the operating system is through the control function, which supplies amplification of operating system capabilities, such as interrupt request processing, equipment interfaces, TTY message processing, coordination and control of application programs.

3.3.5 Configuration/Installation Design of the Monitor Stations

This section includes those requirements and standards for the installation of the three GPS Monitor Stations. As indicated in paragraph 3.2, these stations will be located as follows:

a. U. S. Army Fort Richardson, Alaska

b. U. S. Naval Communications Station, Wahiawa, Hawaii

c. Transportable to a suitable facility

TABLE 3-3

TYPICAL COMMUNICATIONS LOAD SUMMARY, ELMENDORF TO MCS

	UNITS	Φ I
TRACKING OPERATION/DAY	HRS.	14.95
AVG. LOAD/OP. HOUR	SAT.-HR.	2.37
TRK. DATA/OP. HOUR	BITS	95,558
STATUS/MET. DATA/OP.HR.	BITS	17,905
COMM. TIME/OP. HOUR	MIN.	1.26
TRK./STATUS DATA/DAY	MBITS	1.697

3.3.5.1 Site Configuration. The Monitor Stations consist of two standard equipment racks, a teletype (TTY), and one L-band conical receiving antenna integrated into the existing facilities at the various locations.

The Fort Richardson monitor station racks and TTY will be installed in building 35-750 with the L-band receiving antenna mounted on the roof of the building. The roof mounting will provide freedom from obscura above 5 degrees horizon in all azimuth positions, except at bearings of 88 degrees and 113 degrees (true). The obscura in these two positions are 6° - 0" and 6° - 14", respectively. These exceptions are considered acceptable for the accomplishment of the monitor station's mission.

The Hawaii monitor station racks and TTY will be installed in building 387, with the L-band receiving antenna and meteorological equipment installed on a 40-ft high structure tower. The location of the tower will permit freedom from obscura above a 5 degrees horizon in all azimuth positions. The structure will be guyed to limit swaying at the top to less than ±12 inches maximum in 120 knot winds.

Room Arrangements

The Monitor Station equipment racks and TTY will be installed in the technical equipment rooms of building 35-750 in Fort Richardson as shown in Figure 3-20, and of building No. 387 of the Naval Communications station, as shown in Figure 3-21. The Fort Richardson building 35-750 has cable trenchways recessed into the concrete floor with 1/4" checkered steel plate covers. The Hawaii building has false flooring of raised panel construction above a concrete slab. Racks will be mounted in a manner that will ensure mechanical stability under worst case conditions of equipment chassis slide positioning or anticipated seismic loading. Adjacent racks will be fastened together at top and bottom with fronts aligned to within 1/16 inch.

Rack Arrangement

The two racks of Monitor Station equipment will be the same at all locations. Rack elevation configurations for the two racks are shown in Figure 3-22. The racks will be standard 19-inch panel width, with overall dimensions of 24 inches wide, 30 inches deep, and 84 inches high. Access will be through the bottom of the racks.

Weather Measuring Instrumentation Installation

Weather measuring instruments will be installed in a double wall shelter, mounted at 30 feet above the surrounding ground level. The shelter will be provided with a long life fan for continuous asperation of temperature and humidity sensors. Air inlet for the fan supply will be screened and filtered to minimize dust and insects from entering the enclosure. Required power and instrumentation cabling will be buried underground between the tower and the building.

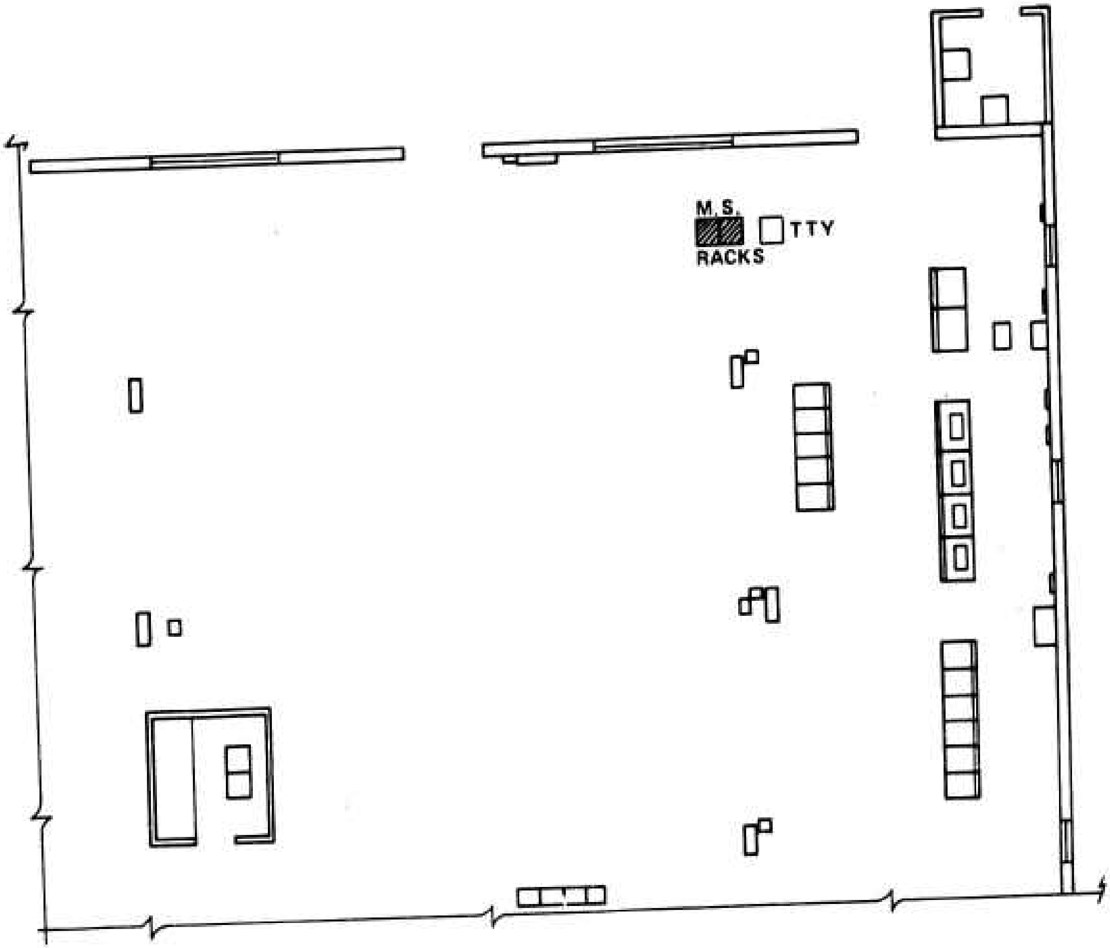


Figure 3-20 Monitor Station Racks (Typical Arrangement at Elmendorf)

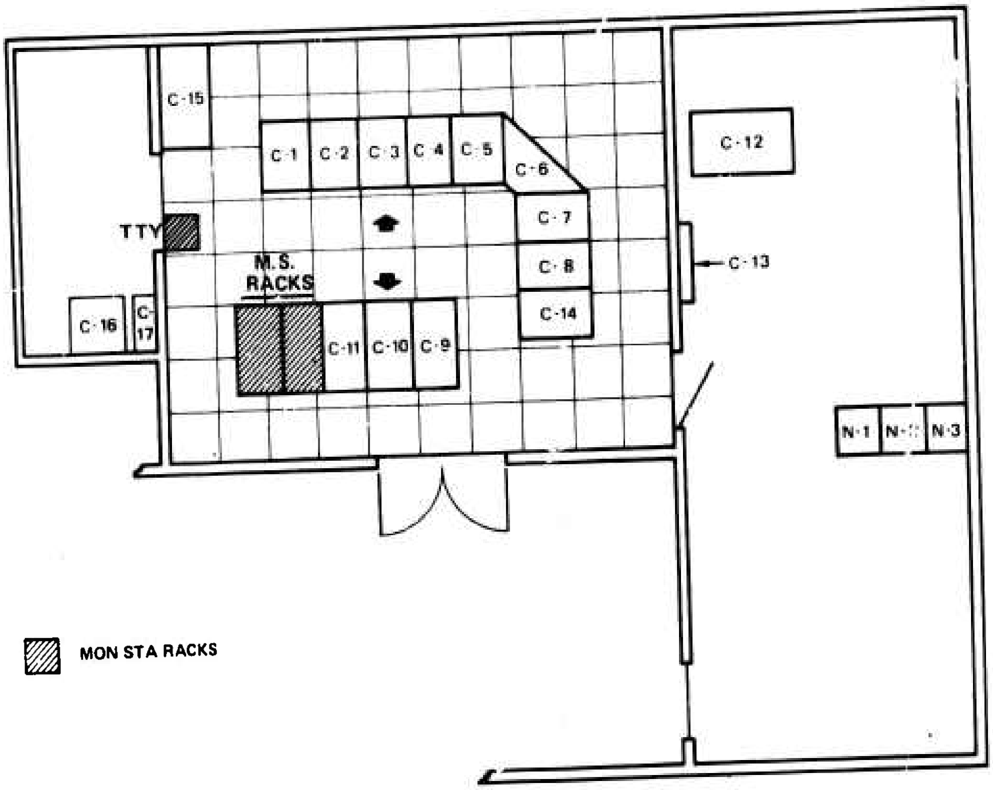


Figure 3-21 Monitor Station Racks (Typical Arrangement at Wahiawa)

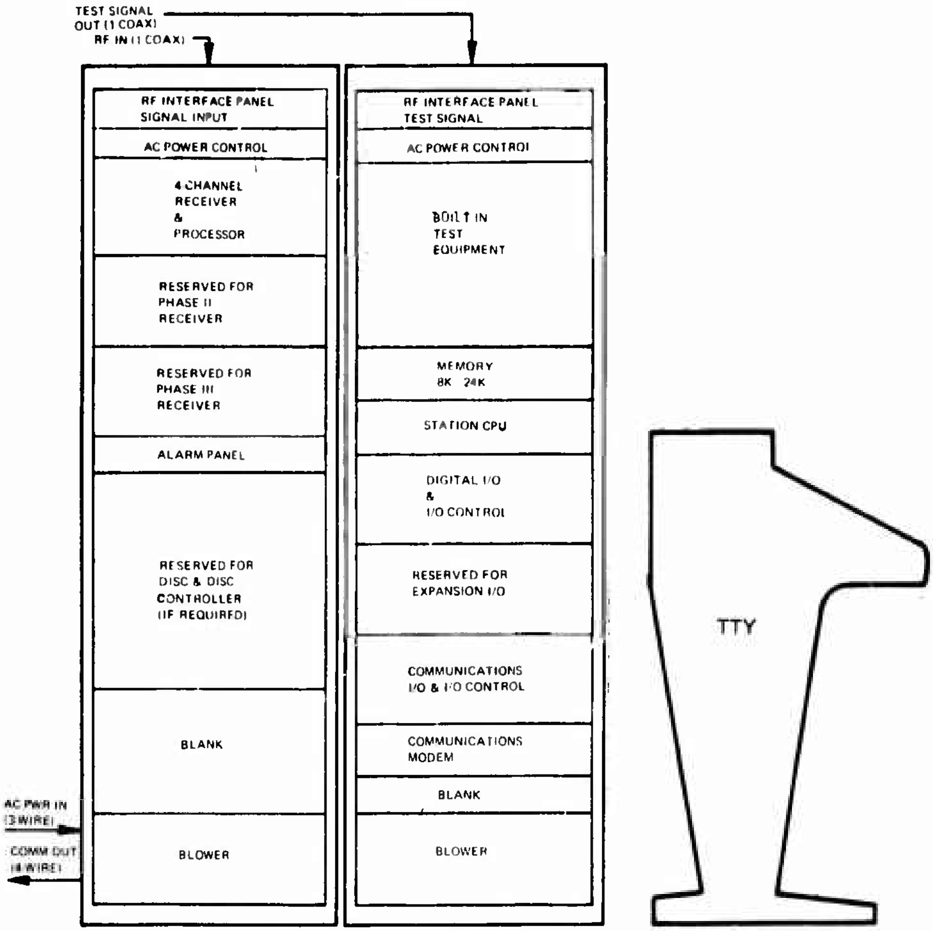


Figure 3-22 Monitor Rack Elevations

3.3.5.2 Environment. Ample capacity presently exists at Fort Richardson building 35-750 and NAG building 387 to provide air conditioning or heating as required for the Monitor Stations. Heat dissipation from the equipment is minimal. A comparison of average yearly climatic conditions at the two locations show the following:

Item-Average Yearly	Fort Richardson	NAG Hawaii
Number of days above 70° F	12	300
Number of days below 0° F	42	0
Number of days below 50° F	320	30

3.3.5.3 Construction Standards. The facilities construction standards applied to the MCS installation will, in general, apply to the MS. Refer to paragraph 3.4.5 and subparagraphs thereto.

3.3.5.4 Lightning Protection. Lightning protection meeting the requirements of the Lightning Protection Code NFPA No. 78 will be provided as required for the L-band antenna support and the weather instrumentation tower.

3.3.5.5 Obstructions to Air Navigation. The L-band receiving antenna support and the weather instrumentation tower will be lighted and/or painted as determined by Federal Aviation Regulations, Part 77, and in accordance with the Federal Aviation Agency (FAA) publication entitled, Obstruction Marking and Lighting.

3.4 MASTER CONTROL STATION DESCRIPTION

This subsection documents the hardware and software baseline configuration for the GPS master control station. This configuration, like the monitor station configuration, was developed with a view to both cost and requirements. Again, the result is a configuration which, by-analysis, meets its allocated requirements and does so at a minimum expense to the Government.

3.4.1 Master Control Station Requirements

Once again the reader should recall the CS data flow -- in particular the "process/MCS" relationship. That is, the principal function of the MCS is to process navigation data forwarded to it from the MS. However, to implement its prime function and to support overall CS operations, the MCS has been allocated a number of subsidiary functions in addition to navigation data processing. Moreover, the MCS is also allocated specific interface and availability requirements.

Table 3-4 focuses on the functional requirements which are to be met by the MCS hardware and software. Referring to the table, note the preponderance of functions allocated to software -- it is,

TABLE 3-4

ALLOCATION OF CS FUNCTIONAL REQUIREMENTS TO THE MASTER CONTROL STATION

FUNCTION	Master Control Station HARDWARE CI NO. 237273	Master Control Station SOFTWARE CPCI NO. 237309	Master Control Station PERSONNEL	Upload Station HARDWARE CI NO. 237277	Upload Station SOFTWARE CPCI NO. 237313	Upload Station PERSONNEL	Monitor Station HARDWARE CI NO. 237275	Monitor Station SOFTWARE CPCI NO. 237311	Monitor Station PERSONNEL	Tele Com CI NO. 237279
Control Segment Operations										
• Segment Initialization and Recovery		X	X			X				
• System Scheduling		X	X							
• Communications Function		X	X		X			X		X
• Display and Control Function	X	X		X	X		X	X		
• Status Monitoring Function	X	X	X	X	X	X	X	X		
Navigation Data Collection										
• System Calibration Data		X								
• Space Vehicle Tracking Data				X	X		X	X		
• System Time Standard	X	X								
• Space Vehicle Health and Status Data		X								
• Space Vehicle Access Key		X								
Navigation Data Processing										
• Tracking Data Preprocessing		X								
• Reference Ephemeris Generation		X								
• SV Ephemeris Prediction		X								
• SV Clock Prediction		X								
• Almenac Data Generation		X								
• Upload Message Generation		X								
Space Vehicle Navigation Subsystem Control										
• Navigation Upload Control		X	X		X	X				
• Upload Message Validation		X			X					
• Upload Message Transmission				X	X					
• Upload Verification and Retry				X	X					
System Test/Calibration/Maintenance										
• Control Segment Calibration				X		X	X		X	
• Ionospheric Data Collection		X								
• Navigation Performance Evaluation		X			X			X		
• Space Vehicle Signal Quality Monitoring				X	X					
• Support Software Development	X	X								
• Segment Readiness Testing	X	X		X	X		X	X		
• Segment Evaluation Testing	X	X	X	X	X		X	X		
• Logistics Support			X							

incidentally, this preponderance that places software ahead of hardware in the subsequent text addressing the MCS configuration. Further, one notes that the MCS software; and to a much lesser extent, the hardware; services all the major CS functions, ie, segment control, data collection, data processing, uploading and testing/calibrating. The specific allocated functions shown in the table are examined individually below followed by a review of MCS interface and availability requirements.

3.4.1.1 Tracking Data Pre-processing. The MCS will be capable of preprocessing SV ranging data to correct ionospheric, tropospheric, and equipment ranging biases. It will be capable of removing wild points and smoothing this data to a level necessary to support the error budget established for the CS.

3.4.1.2 Reference Ephemeris Generation. The MCS will support the generation of reference ephemeris data by sending smoothed L-band pseudo-ranging data to the Naval Weapons Laboratory (NWL) on a weekly basis. In no more than 3 days after data transmittal NWL will send the MCS 15 days of predictions of two types of data:

a. Reference ephemerides for up to 24 satellites in F and G coordinates at 15 minute intervals.

b. Ephemeris partials for up to 24 satellites in F and G coordinates at 15 minute intervals.

The MCS will maintain this data in the data base for retrieval by all programs which require high accuracy ephemeris.

3.4.1.3 Space Vehicle Ephemeris Prediction Generation. The MCS will be capable of generating predictions of the SV ephemerides for up to 24 satellites. These predictions will be based upon estimates of the satellite orbits computed from smoothed L-band pseudoranging data and the reference ephemeris. Predictions will be expressed as polynomials in time in an earth-fixed/earth-centered coordinate system. The MCS will be capable of predicting the ephemeris of 12 SVs within one hour of receipt of valid tracking data The prediction span will be a minimum of 2 days. The rss position error between predicted ephemeris and actual observed reference ephemeris will not exceed 50 meters after one day.

3.4.1.4 Space Vehicle Clock Prediction. The MCS will generate predictions of the satellite clock parameters (bias, drift, drift rate as required) relative to the system master clock. These predictions will be based upon estimates of past clock behavior computed from smoothed L-band pseudoranging data. Predictions will include compensation for relativistic effects, and will be expressed

as polynomials in time. The prediction span will be a minimum of 2 days. The MCS will be capable of generating a new prediction within 15 minutes of the receipt of new tracking data. The MCS will maintain data for display which indicates the behavior of each clock in the system relative to the system time reference and universal time.

3.4.1.5 Almanac Data Generation. The MCS will be capable of generating a satellite vehicle location almanac good for a 30 day period to an absolute satellite position error of 30,000 meters. The MCS will maintain the almanac data as the basic source of low accuracy ephemeris.

3.4.1.6 Upload Message Generation. The MCS will be capable of generating SV navigation subsystem messages containing the following data types:

a. Ephemeris predictions

b. Clock predictions

c. Almanac predictions

d. SV navigation subsystem control commands

The MCS will be capable of attaching SV storage locations to portions of the message, of attaching secure keys to the messages, and providing appropriate formatting and error checking data. Messages will be stored for analysis and historical purposes in the MCS data base.

3.4.1.7 Upload Control. The MCS will provide operational personnel the capability to control in real time all facets of the upload process. This will include the capability to:

1. Send SV messages to the upload station

2. Start and stop the SV transmission process

3. Set the reject level

4. Bypass verification and echo checking

5. Point the antenna

The MCS will provide appropriate responses to all control actions undertaken by an operational position. Capability will be provided to transmit on a message, frame, block or command basis. The control function will be designed to minimize operator intervention so as to achieve a complete message upload within 10 minutes.

3.4.1.8 Upload Message Validation. The MCS will be capable of validating the ability of an SV navigation subsystem message to support user navigation. This validation will be performed on an individual vehicle basis, and will require no more than 3 minute of execution time. The process will include validation of navigability, error detection data, acceptability of format. Validity will be displayed to operational personnel in terms of go/no go indicators and in terms of specific error criteria.

3.4.1.9 System Calibration Data. The MCS will provide for storage, retrieval and processing of system calibration data. Monitor Station locations and geopotential coefficients will be generated periodically by NWL. SV transmitter biases, MS range biases, and other navigation related parameters will be stored and used as required.

3.4.1.10 System Time Standard Generation. The MCS will maintain the GPS time standard to which all other user, satellite and control segment clock/time biases are referred. The time standard will incorporate the best commercially-available atomic standards capable of providing at least an accuracy of ±7 parts in 10^{12}, a settability of 1×10^{-13} and a short term (1 sec avg) stability of 5×10^{-12}. The time standard will be fully redundant and be capable of operating at least 24 hours from an internal power source.

3.4.1.11 Space Vehicle Health and Status Data Collection. The MCS will store SV health and status data collected by the AFSCF and provided to the MCS via the telecommunications network. Vehicle health data will be received as satellite telemetry converted to engineering units. Vehicle status data will include predicted orbit adjust parameters, acceleration biases due to outgasing and attitude control reactions and planned SCF command activities.

3.4.1.12 Space Vehicle Access Key Collection. The MCS will receive SV Access Control words from the SCF in support of the SV Navigation Subsystem Message Generation Process. Sufficient data will be provided to allow operation of each satellite for at least one week. To avoid transmission security violations, this data will be communicated in terms of indices to a common secure key book.

3.4.1.13 Segment Initialization and Recovery. The MCS will be designed to permit initiation of system operation from a cold start within 60 minutes. The MCS will be capable of recovery from a fault condition within 60 minutes. Under no circumstances will the MCS be required to go more than 24 hours back in its data base to recover from a fault condition.

3.4.1.14 System Scheduling. The MCS will be capable of scheduling all operations of the segment. It will provide individual schedules for the entire segment, the MCS, each MS, and the US. It will provide for all points within visibility of a GPS satellite. This data will include for each point as a function of time, satellites visible, corresponding GDOP, expected navigation error. The system schedule will support the segment control function in scheduling SV tracking data collection, SV navigation subsystem control, and navigation message generation.

3.4.1.15 Communications. The MCS will be capable of controlling all data communications between the master control station and the following remote stations:

a. Monitor stations (3)

b. Upload station

c. Satellite control facility

d. Remote computing facility

This function will include the establishment and maintenance of communications control between the remote stations and MCS, the transmission of data messages from the MCS to the remote stations, and the reception of data messages at the MCS from the remote stations.

The communications function will be capable of supporting synchronous data transmission over five full duplex 2400 bps commercial data lines between the master control station and:

3 monitor stations

1 upload station

1 satellite control facility

The communications interface between the remote computing facility and the master control station will be via half duplex dial-up commercial voice frequency lines.

In support of the segment maintenance function, the communication function will provide for alternate voice order-wire and/or administrative text transmission between CS operating locations and personnel.

3.4.1.16 Display and Control. The MCS will be designed to provide efficient interaction between operations personnel, computer programs and segment elements. Control and display functions will be implemented through the use of commercially available computer peripheral equipment. To the largest degree possible, control of the

system will be effected by operator selection of displayed control alternatives.

3.4.1.17 Status Monitoring. The MCS will be designed to provide on-line monitoring of the status of all critical segment functions and elements. Current status information will be summarized and displayed to segment operators. Detailed status data will be available upon operator request. Status will be maintained and displayed for each monitor station, the upload station, the MCS, and each SV. Status of the MCS will include the computer, the communications equipment and the control and display facilities.

3.4.1.18 Ionospheric Data Collection. The MCS will provide for storage of ionospheric data required to evaluate potential single frequency ionospheric correction models. This data base will include as a minimum: integrated electron density, station location: latitude, longitude, local satellite azimuth and elevation, GMT time of day, day of year, and year.

Ionospheric data will be converted to engineering units, formatted for convenient off-line batch processing, and stored on tape. It will be possible to produce a printed record of data currently in storage or of data previously recorded.

3.4.1.19 Navigation Performance Evaluation. The MCS will provide operations personnel with information required to monitor and evaluate GPS navigation performance. This information will be derived from the navigation data base and will be available to operations personnel on demand. Critical parameters will be recorded for use in off-line analysis of user navigation tests. As a minimum, this function will provide:

a. A measure of the residuals between known monitor station locations and locations determined by processing received SV L-band signals; this measure will also be available as user equivalent range error (UERE) normalized for GDOP.

b. A measure of the residuals between predicted satellite ephemerides and pre-processed tracking data.

c. A measure of the residuals between raw tracking data and smoothed tracking data.

d. A measure of the error between the latest observed SV clock state and the state predicted by clock parameters in the navigation data frame.

e. A measure of residuals between the estimate of SV ephemerides at the latest epoch and the ephemerides which were predicted for that epoch 24, 48, and 120 hours before.

f. A measure of the residuals between the estimate of SV clock state at the latest epoch and the state which was predicted for that epoch 1, 4, 12 and 24 hours before.

g. A measure of the physical, ie, uncorrected, synchronization error between the GPS time standard and all MS, US and SV clocks.

h. An estimate of current GDOP at the MCS, each MS and at test locations defined by operations personnel.

3.4.1.20 Support Software Development. The MCS will provide the hardware and software necessary to support field modification and development of operational programs as well as development and use of off-line analysis programs. It will be possible to operate these programs concurrently with the operational software without interfacing with or degrading the operational functions.

3.4.1.21 Segment Readiness Testing. The MCS will provide, in support of the operations function, the capability to rapidly determine the readiness of the segment to support its mission. This function will exercise all elements of the segment while in an operational configuration, independent of the space vehicles. It will be possible to initiate this test function from an operators console. Test results will be provided in the form of a go no-go indication within 2 minutes. No other operator actions will be required to initiate the complete this function. Lower level tests, ie, upload station, monitor station readiness test will also be provided. These tests will be initiated in the various maintenance areas in order to radiply isolate a fault detected at the system level.

3.4.1.22 Segment Evaluation Testing. The MCS design will provide, in support of the system maintenance function, the capability for periodic evaluation of critical MCS parameters. Performance of these tests will be classified as maintenance actions and will require the attention of maintenance personnel. The design will satisfy the following requirements in support of this function:

a. It will be possible to complete all scheduled periodic maintenance without connecting or disconnecting cables or equipments normally required for operational support.

b. Wherever it is necessary to connect external equipment, appropriate test connectors readily available, will be provided. These test connections will be isolated from operational circuits so that connections or disconnections does not affect the operating characteristics of the system.

3.4.1.23 Interface Requirements. All of the external MCS interfaces are implemented via the telecommunications network. Hence, the MCS hardware will be required to present six input/output ports with characteristics compatible with the input/output characteristics of the network terminal equipment. In addition, the software communication function will be required to provide message formats and protocol that satisfy the requirements of the control segments interface control documentation (HZ-237302, Interface Control Drawing for Ground Communications).

3.4.1.24 Availability Requirements. Table 2-3, in the preceding section, indicates that MCS equipment should be sufficiently reliable to support an MTBF assessment of 50 hours, and the equipment maintainability should support an MTTR of 4.05 hours.

3.4.2 Interpretation of Requirements. Most of the functional requirements imposed on the MCS are direct and unambiguous -- the MCS is clearly embodied in software with the MCS hardware simply serving to host the many software functions. Nevertheless, it is important to note several items, perhaps hidden in the long list of allocated, functions, which impact the hardware design/selection.

First one notes that many of the software functions develop data to added to the MCS data base. Considering the number of functions filling the data base one can expect the MCS to have a large mass storage capacity. In addition, some of the data in the data base are to be retained for extended periods (eg, ionospheric and navigation performance data) and this imposes a requirement for an inexpensive long-term storage medium such as magnetic tape.

Certain software functions require interaction with an operator/analyst thereby establishing a requirement for some form of man/machine interface device. Other functions such as scheduling are supported by hardcopy -- hence a requirement for a printing device. Likewise, the software development function requires support from card a reader, and out of the software emerge requirements for a number of computer peripheral devices.

Within the system time standard generation function resides the requirement for a formidable hardware equipment group, viz., dual cesium atomic time standards with all their supporting electronics. One sees, then, that although most of the MCS functional requirements are borne by software the MCS will still comprise a considerable array of hardware.

3.4.3 Master Control Station Configuration

A block diagram of the MCS appears in Figure 3-23. In this figure five major components are identified, viz:

a. MCS Data Processing Equipment Group

b. Data Processing Peripheral Equipment Group

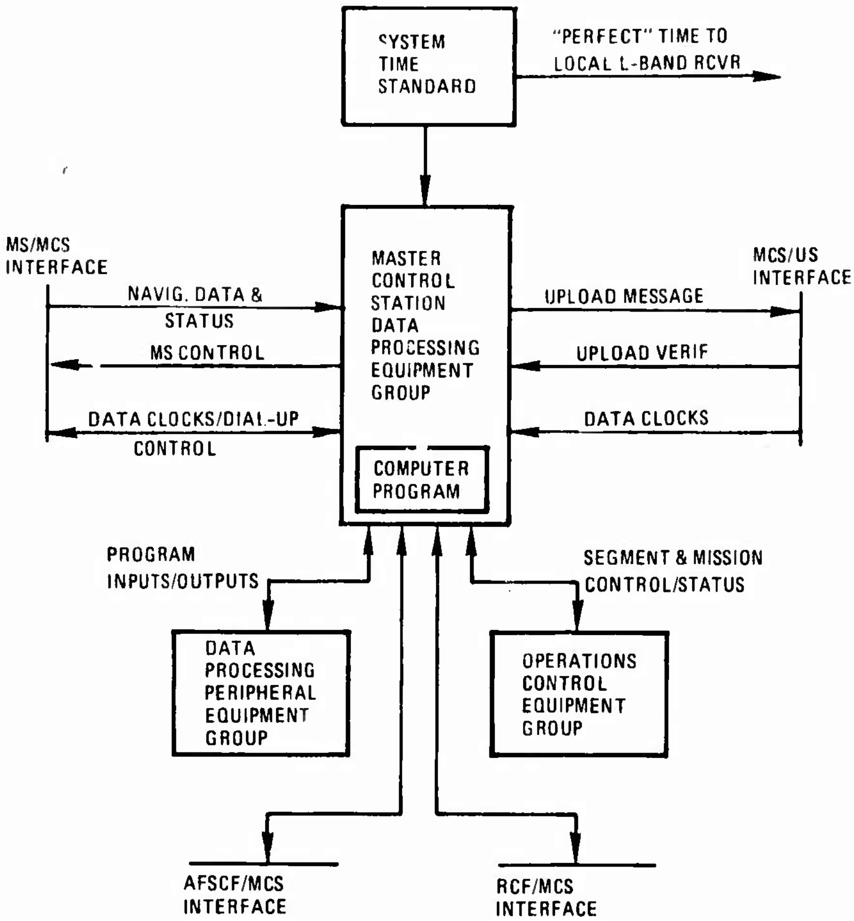


Figure 3-23 Master Control Station Block Diagram

c. Operations Control Equipment Group

d. System Time Standard

e. MCS Computer Programs/Software

Because of its prominence at the MCS a description of MCS software precedes the presentation of the MCS hardware baseline.

The software in the MCS provides the tools and environment needed by the operational support staff to accomplish the mission of the control segment. Eight primary functions, each implemented by one or more computer programs, are provided. These functions are:

a. Collection and Processing of Monitor Station Data

b. Ephemeris and clock state estimation

c. Ephemeris, Clock, and Almanac Prediction

d. Upload Message Generation and Upload Control

e. Navigation performance evaluation

f. System status monitoring and fault detection

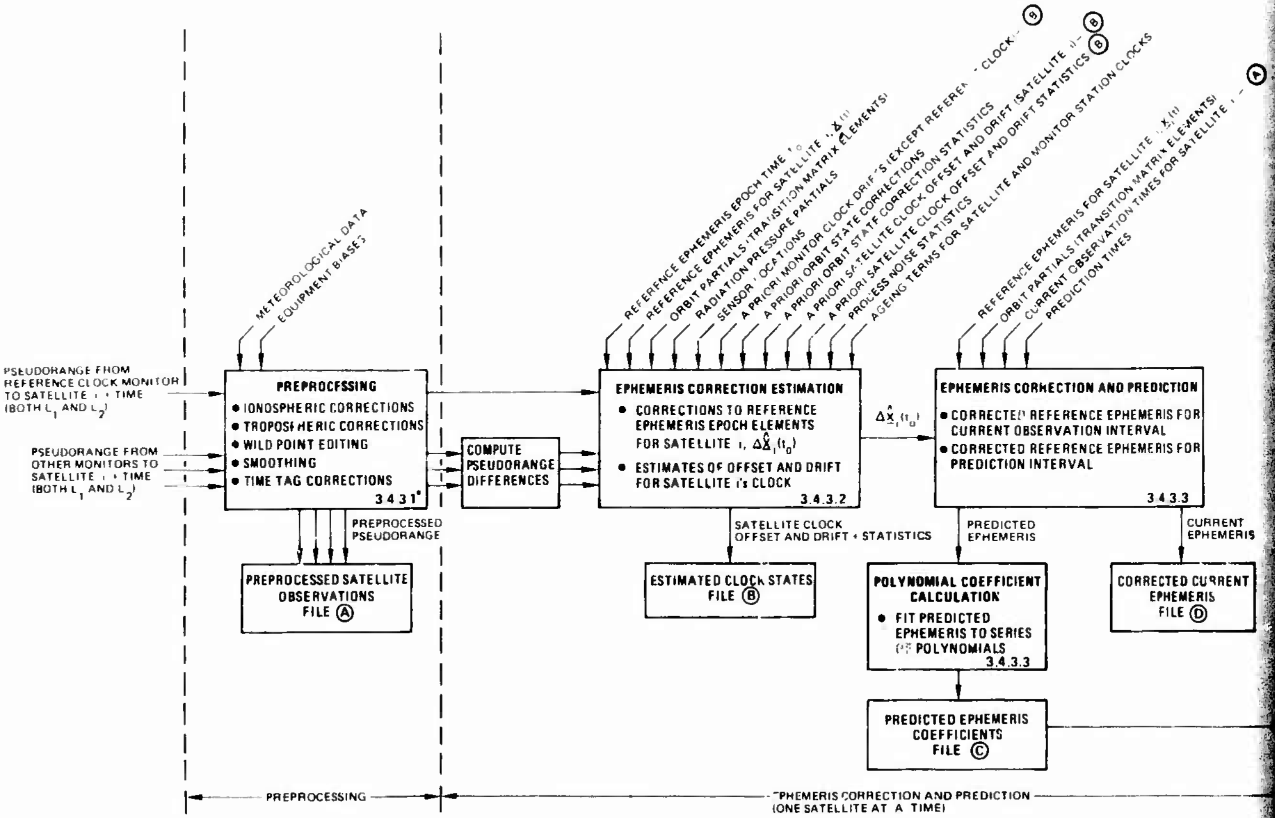
g. System scheduling

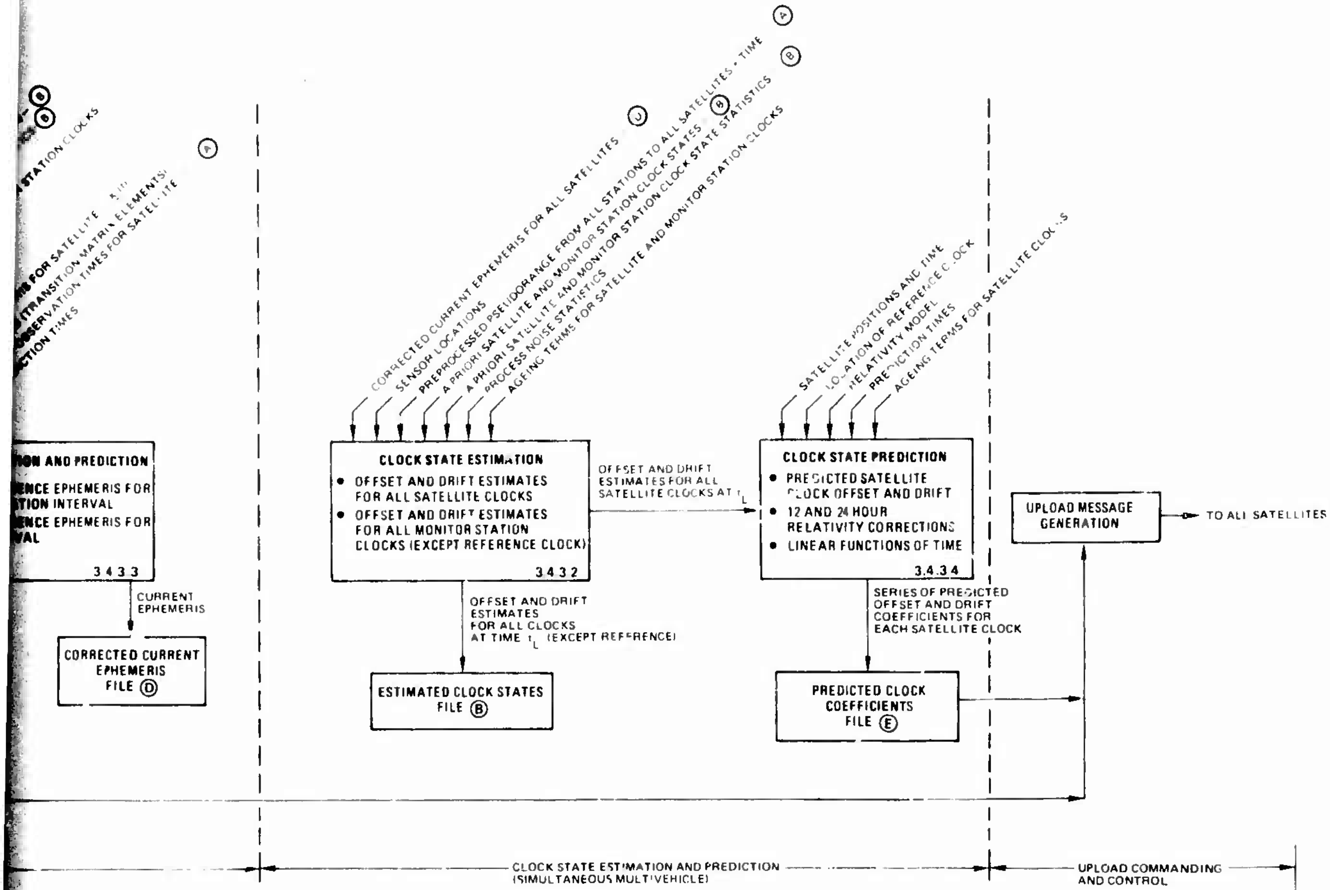
h. Operations Control

As a guide through the discussion of the critical functions, the reader is referred to Figure 3-24 which shows these functions positioned along the critical flow path for software. In addition, refer to an earlier figure -- Figure 3-1 -- which reveals an equivalent path through the control segment hardware.

To establish the overall data flow and the control interrelationships in the MCS software it is convenient to describe the operational flow in a typical daily timeline. Referring to Figure 3-24, Monitor Station data, pseudo ranging, status, meteorological, and navigation data enters the MCS in response to a polling command issued to the Monitor Station by the MCS.

Tracking data and station status data are separated and stored in the corresponding data base files. The tracking data is then preprocessed for use in generating satellite ephemeris and clock state vectors. This preprocessing includes the removal of equipment biases, atmospheric delays, and clock biases, and the smoothing of resultant tracking data observations. This processing cycle continues on a periodic basis (1 to 3 hour interval) as defined by the system schedule. On the same cycle, these smoothed observations are used to estimate the satellite orbits and the state of the satellite and ground system clocks. This estimation process is done in conjunction


METEOROLOGICAL DATA
EQUIPMENT BIASES
PSEUDORANGE FROM REFERENCE CLOCK MONITOR TO SATELLITE i • TIME (BOTH L1 AND L2)
PSEUDORANGE FROM OTHER MONITORS TO SATELLITE i • TIME (BOTH L1 AND L2)
PREPROCESSING
• IONOSPHERIC CORRECTIONS
• TROPOSPHERIC CORRECTIONS
• WILD POINT EDITING
• SMOOTHING
• TIME TAG CORRECTIONS
3.4.3.1
PREPROCESSED PSEUDORANGE
PREPROCESSED SATELLITE OBSERVATIONS FILE Ⓐ
COMPUTE PSEUDORANGE DIFFERENCES
REFERENCE EPHEMERIS EPOCH TIME
REFERENCE EPHEMERIS FOR SATELLITE
ORBIT PARTIALS (TRANSITION MATRIX ELEMENTS)
RADIATION PRESSURE PARTIALS
SENSOR LOCATIONS
A PRIORI MONITOR CLOCK DRIFTS (EXCEPT REFERENCE CLOCK)
A PRIORI ORBIT STATE CORRECTION STATISTICS
A PRIORI ORBIT STATE CORRECTIONS
A PRIORI SATELLITE CLOCK OFFSET AND DRIFT (SATELLITE i)
A PRIORI SATELLITE CLOCK OFFSET AND DRIFT STATISTICS
PROCESS NOISE STATISTICS
AGEING TERMS FOR SATELLITE AND MONITOR STATION CLOCKS
EPHEMERIS CORRECTION ESTIMATION
• CORRECTIONS TO REFERENCE EPHEMERIS EPOCH ELEMENTS FOR SATELLITE i
• ESTIMATES OF OFFSET AND DRIFT FOR SATELLITE i's CLOCK
3.4.3.2
SATELLITE CLOCK OFFSET AND DRIFT + STATISTICS
ESTIMATED CLOCK STATES FILE Ⓑ
REFERENCE EPHEMERIS FOR SATELLITE
ORBIT PARTIALS (TRANSITION MATRIX ELEMENTS)
CURRENT OBSERVATION TIMES FOR SATELLITE
PREDICTION TIMES
EPHEMERIS CORRECTION AND PREDICTION
• CORRECTED REFERENCE EPHEMERIS FOR CURRENT OBSERVATION INTERVAL
• CORRECTED REFERENCE EPHEMERIS FOR PREDICTION INTERVAL
3.4.3.3
PREDICTED EPHEMERIS
CURRENT EPHEMERIS
POLYNOMIAL COEFFICIENT CALCULATION
• FIT PREDICTED EPHEMERIS TO SERIES OF POLYNOMIALS
3.4.3.3
CORRECTED CURRENT EPHEMERIS FILE Ⓓ
PREDICTED EPHEMERIS COEFFICIENTS FILE Ⓒ
PREPROCESSING
EPHEMERIS CORRECTION AND PREDICTION (ONE SATELLITE AT A TIME)



NOTE NUMBERS APPEARING IN LOWER RIGHT HAND CORNERS OF FUNCTION BLOCKS REFER TO APPROPRIATE CPCI SECTIONS

Figure 3-24 Data Processing Critical Path

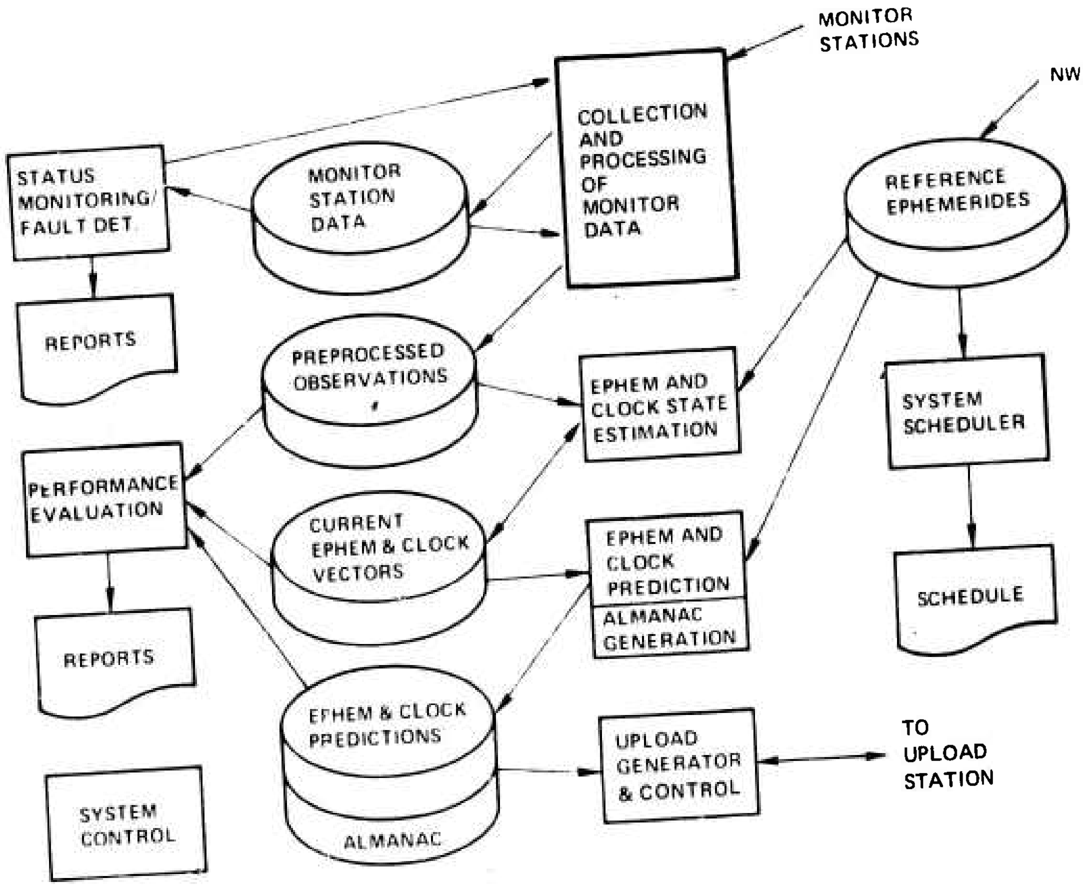


Figure 3-25 Master Control Station Overview

with an externally generated reference ephemeris as discussed in Paragraph 3.4.3.2.

In preparation for the daily upload process, the satellite orbit are predicted, and formed into a five day ephemeris, again in conjunction with the reference ephemeris. Each one hour segment of this cartesian ephemeris is fit by three polynomials in time to produce a set of coefficients which represent the satellite position. Similarly, clock bias is predicted over the same 5 day span, including relativistic effects, and fit by polynomials to obtain one hour sets of clock bias coeffients for each satellite clock. Also to be prepared for the upload message, but on a much less frequent basis (every 30 days), the acquisition almanac is generated for each satellite as a set of mean orbital elements derived from the reference ephemeris.

The upload message generator composes the upload messages for all satellites using the ephemeris polynomials, clock polynomials, acquisition almanac and upload control commands required. These messages are stored in a file for later transmission to the upload station. At the time of the upload pass, the messages are retrieved and sent via communications line to the upload station. Transmission to the satellite maybe controlled from an operations console at the MCS or by upload station personnel. The accept/reject data is received back from the upload station via the communications line and is used to maintain a current map of the navigation payload memory for each satellite.

System navigation performance is periodically evaluated. This function uses the processed tracking data and the ephemeris polynomials and clock corrections currently in use to compute positions for the monitor stations. It also displays the navigation solutions obtained directly from the monitor processer. Associated error analysis data such as GDOP factors are also computed. Reports are generated which provide orbit/navigation analysts with data needed to evaluate system performance.

The system status monitoring and fault detection fucntion provides status displays for each station in the Control Segment and for each of the satellite under control. These displays are derived from status data gathered from each station and from telemetry data obtained from the GPS software executing in the SCF. This function also plays an active role in the Control Segment status evaluation process by conducting real-time closed looped tests in conjunction with the monitor and upload stations.

The system scheduling process is run on a weekly basis, providing detailed scheduling data for the coming week, and less detailed for the following 21 days. It uses the reference ephemeris to schedule MCS activities (monitor polling, upload generation, maintenance, etc.), monitor station tracking, and upload station passes. A system schedule and individual station schedules are produced and stored in the data base. Corresponding hard copy reports are generated for use by system operation personnel.

The operations control function acts as the system executive, using the system schedule, operator inputs, and the computer's operating system to effect the timely flow of data through the system. It is the primary interface with system operations personnel, providing the capability to bring programs into execution, display and change the data base, dump and restore the data base, and other system control functions.

The previous discussion has attempted to place each of the MCS software functions in perspective against the operational role of the MCS. Figures 3-26, 3-27 and 3-28 show how these processes fit in the operational timelines. The following paragraphs provide a detailed discussion of the processing requirements imposed on each of the functions and some insight into the Philco-Ford design approach.

3.4.3.1 Collection and Processing of Monitor Station Data. All interfaces with the Monitor Stations are controlled by the Monitor Control Program. This program provides two distinct capabilities; control of the collection and processing of operational data associated with the Monitors-pseudoranging, frame data, status data, etc; and control of the station built in test equipment (BITE) for test and diagnostic purposes. Only the first will be discussed in this section. The other function will be discussed under SSTEM Status Monitoring, paragrah 3.4.3.5.

On a periodic basis the Monitor Control Program is called into execution by the system control program as shown in Figure 3-29. On each of these calls the monitor stations are dialed up and requested to transmit the data that has been collected since the last polling operation. Actual control of this transmission process is handled by the Monitor Station component of the communications program which sends the transmission request, accepts the different message types from the monitor, elevates the check sum in each message for errors, and either requests retransmission or stores the message in the appropriate data file. Five separate message types are currently anticipated:

1. Tracking dat -
   pse[illegible] ange
   pseudorange rate
   Vehicle ID
   Time Tag
   L1/L2 flag
2. Vehicle and Monitor Status Data
3. Monitor Station Navigation Solutions (position "fixes")
4. Meteorological Data
5. Text messages produced by maintenance personnel at the monitor station

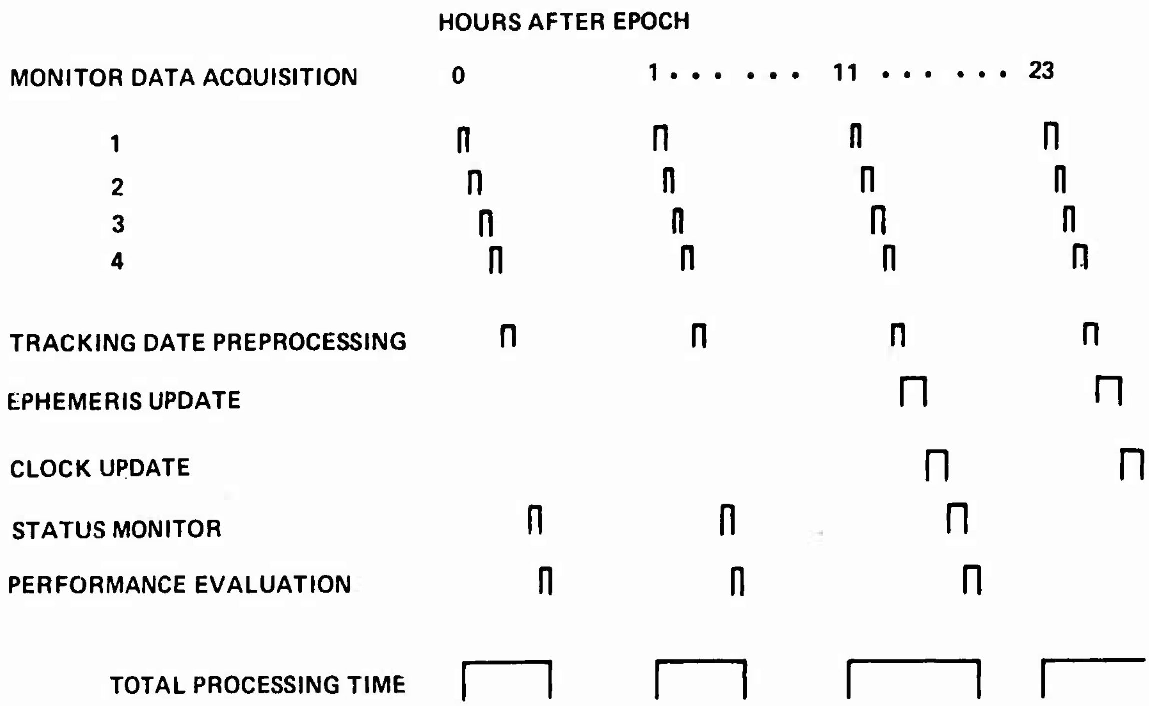


Figure 3-26 MCS Hourly Timeline

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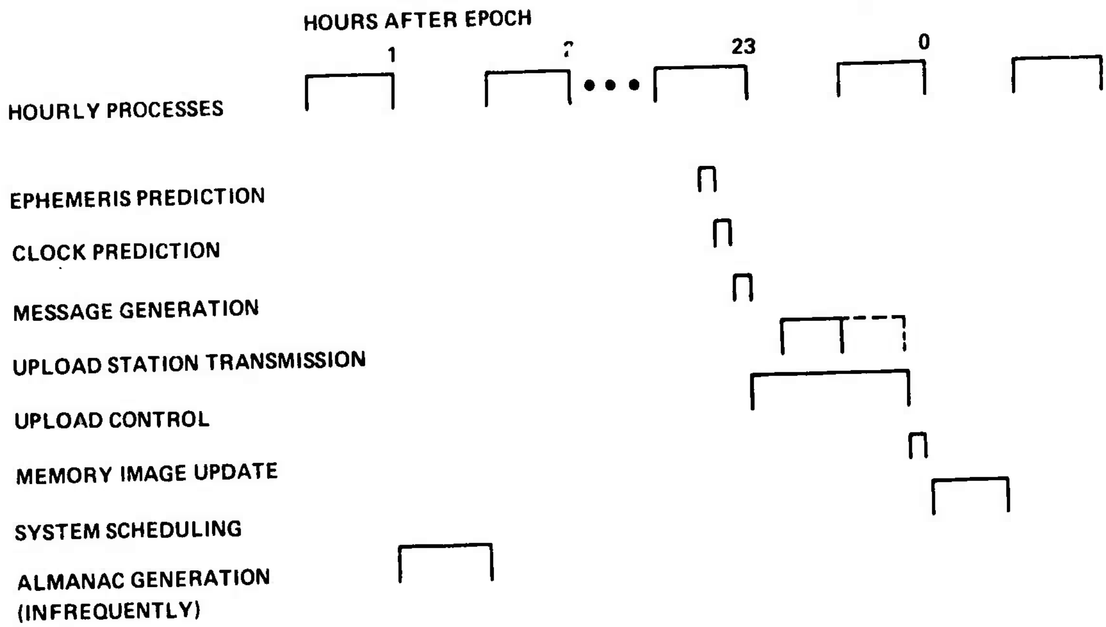

Figure 3-27 MCS Daily Timeline

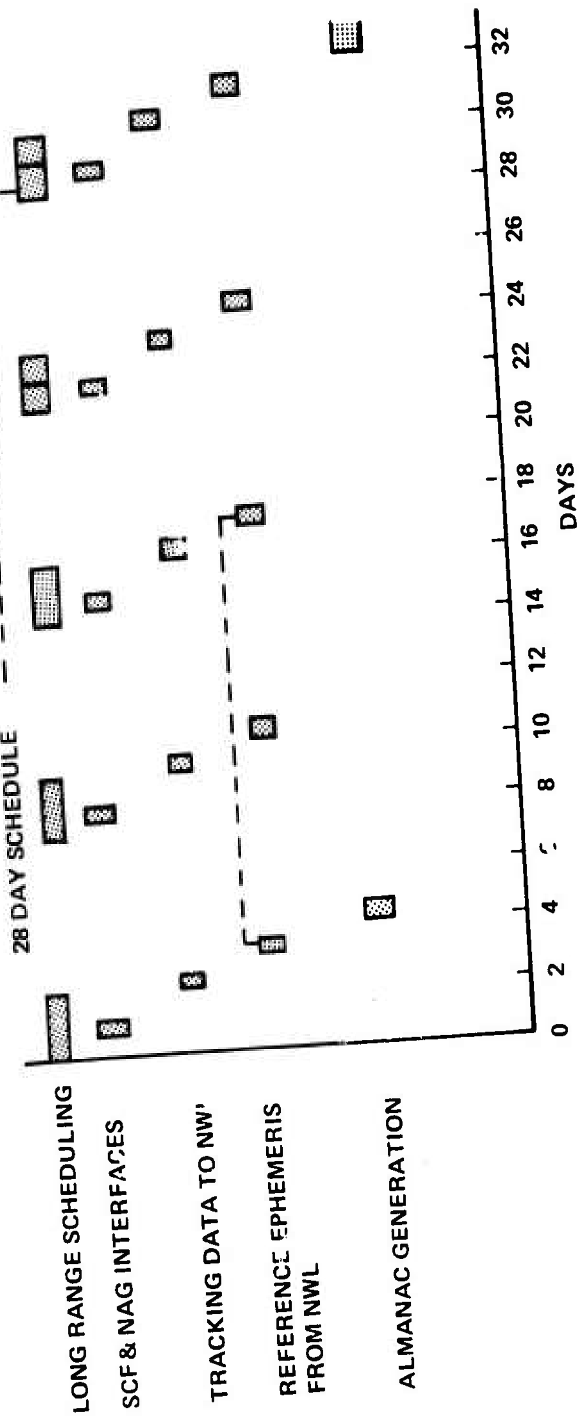

Figure 3-28 Longterm Operational Timeline

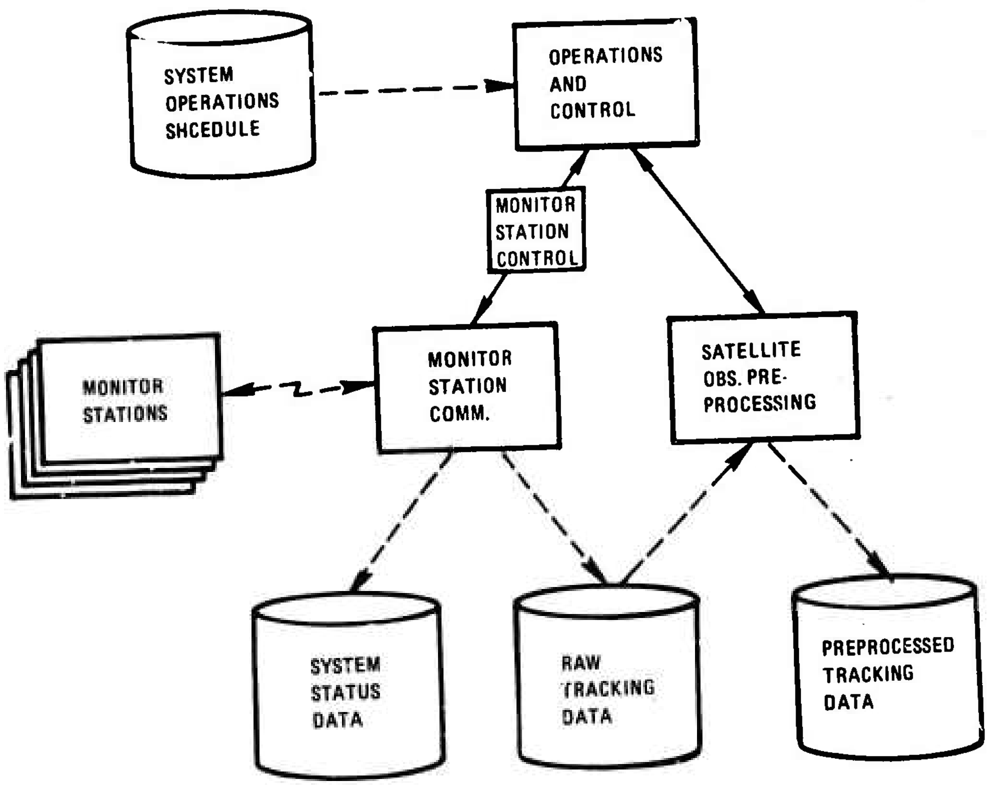

Figure 3-29 Tracking Data Acquisition and Preprocessing

The tracking data is stored in data files by vehicle/by station to make later retrieval efficient.

After the data from a station has been captured on the system data base, communications with the station is terminated, and the tracking data preprocessing program is called to correct these raw observations for systematic bias effects and to edit and smooth them to points on 15 minute centers. (The pseudorange data from the stations occurs on 15 second centers)

First the L2 observations are extrapolated forward using predicted range rate and range "acceleration" to get an L2 observation at the L1 time. A range correction for ionospheric delay is then computed by the equations shown in Figure 3-30. A range correction for tropospheric effects is also computed, and finally these corrections are applied to the pseudorange measurement along with any fixed biases allocated to monitor or satellite hardware.

While the observations have been corrected for possible pseudorange biases, they may contain noise caused by the receiver, multipath, or other phenomenon. To keep wild points from affecting the entire set at observations the editing scheme shown in Figure 3-31 is applied to each observation. All the points which pass this edit over a 30 minute interval are then fit by a low order polynomial which is evaluated at midpoint to get a smoothed observation. This smoothing process is moved forward in time on 15 minute centers in order to obtain smoothed data on 15 minute centers. The resulting observations are stored in data files on a vehicle station basis.

3.4.3.2 Ephemeris and Clock State Determination. The two most critical functions in the MCS software are those which determine the satellite orbits and solve for vehicle clock parameters based on collected tracking data. The extensive analysis and simulation efforts documented in the trade study "Ephemeris Determination Approach" (Vol II Section G) have shown that a distributed processing concept can satisfy the orbit and clock state determination accuracy requirements of the GPS system, in addition to satisfying the desire to minimize the size of the MCS computational environment.

Figure 3-32 shows an overview of the distributed processing concept. The approach provides for computational isolation of the ephemeris determination and clock modelling processes, yet preserves correlated errors (due to station location and geopotential uncertainties) which increase the quality of the GPS navigation products.

Orbit determination is carried out on a single vehicle basis using pseudorange difference values to estimate orbit parameters, and pseudorange data from the "reference clock" monitor station to estimate satellite clock offset, drift, and drift rate. These "reference clock" monitor observations have no offset, drift or drift rate associated with the station clock, so satellite clock parameters

$$\Delta r_i = \frac{r_2^1 - r_1}{f_i^2 \left(\frac{1}{f_2^2} - \frac{1}{f^2} \right)}$$

Δr_i = range correction for the f_i carrier frequency

r_1 = pseudorange of the L1 Signal

r_2^1 = pseudorange of the L2 Signal extrapolated to the time of L1 signal using predicted range rate and acceleration

2 Frequency Ionospheric Correction

$$\Delta r_t = e^{K_1 h + K_2 h^2} \left[\frac{K_3}{\sin E} + K_4 E^{-2.3} \right]$$

Δr_t = range correction

K_1, K_2, K_3, K_4 are functions of temperature pressure and relative humidity at receiving station

h = altitude of receiving station

E = predicted elevation of satellite at receiver

Tropospheric Correction

$$r = r_a + r + r_t$$

where r_a = apparent pseudorange

Figure 3-30 Pseudorange Corrections

If $|\delta| > N\sigma$, the point is rejected.

where δ = range residual, i.e. corrected range minus predicted range

N = a predetermined constant

σ = standard deviatiation of residuals of previously accepted points on the current pass.

Observation Editing

$$r_s = X_0 + X_1 t_m + X_2 t_m^2 + \ldots X_n t_m^n$$

where, r_s = smoothed range

t_m = time of midpoint of smoothing span

X_i = coefficients of least squares polynomial of degree n fitted to the corrected ranges collected over a 15 minute span.

Observation Smoothing

Figure 3-31 Observation Editing and Smoothing

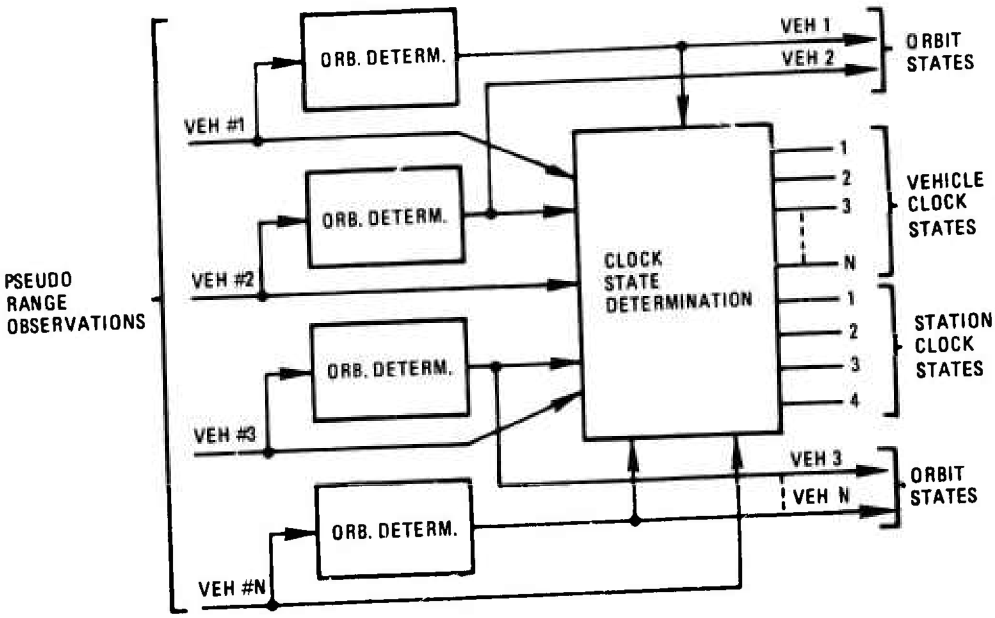

Figure 3-32 Distributed Processing Concept

may be estimated directly. In the baseline configuration, the "reference clock" MS is the Elmendorf L-band equipment since this configuration provides the best ephemeris/clock accuracy. The MCS clock provides "system time", that is, the system timekeeping standard and was so chosen because of its redundancy, alternate power supply, and convenient maintenance. Since satellite clocks must be referenced to the system time standard, the clock prediction process (described in 3.4.3.3) will translate the offset and drift terms computed relative to the "reference clock" into equivalent terms relative to the system time standard. This is primarily a bookkeeping process. This single-vehicle-at-a-time orbit determination process is then followed by a multivehicle clock estimation process to obtain a consistent model for all system clocks using the derived ephemerides and the pseudorange data from all the monitor stations. Further, this concept employs, rather than a full orbit state estimator, an estimator which recursively estimates corrections to an existing ephemeris. This approach allows the time consuming process of orbit integration to be handled in an off line computer on an infrequent basis eliminating the need for a large scale computational facility on line.

Figure 3-33 shows the detailed interfaces in this process. On a weekly basis, corrected/smoothed psuedorange tracking data which has been accumulating in the MCS data base is sent to the remote computing facility at the Naval Weapons Laboratory (NWL) for processing into reference ephemerides. After up to three days NWL returns the following sets of data:

a. Satellite Ephemeris predictions for each satellite over a 15 day period giving an ephemeris point every 15 minutes.

b. An ephemeris of state transition matrices to be used by the online corrector in propagating corrections forward in time.

c. Updates to station location parameters and geopotential parameters used in the correction process.

d. Estimates of GPS clock offsets and drifts (frequency offsets).

These data are retained within the GPS data base and are accessed as required by the Ephemeris and Clock State estimation algorithms.

The estimation algorithm used to compute corrections to the reference ephemeris and to generate improved estimates of system clock states is shown in Figure 3-34. It employs a Carlson Triangular square root recursive filter.

Although several alternative estimation techniques were considered, the triangular square root estimator was chosen over the conventional squential batch least squares estimator because of its added flexibility in modeling GPS process noise, and over other recursive

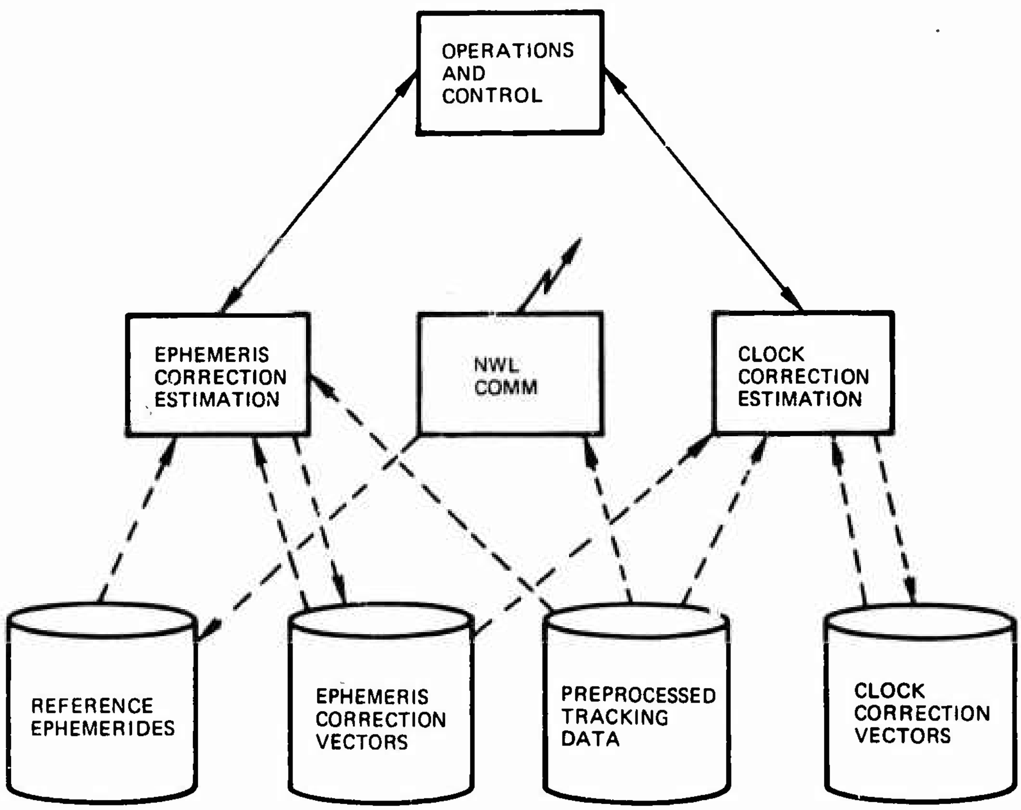

Figure 3-33 Ephemeris and Clock Correction Estimation

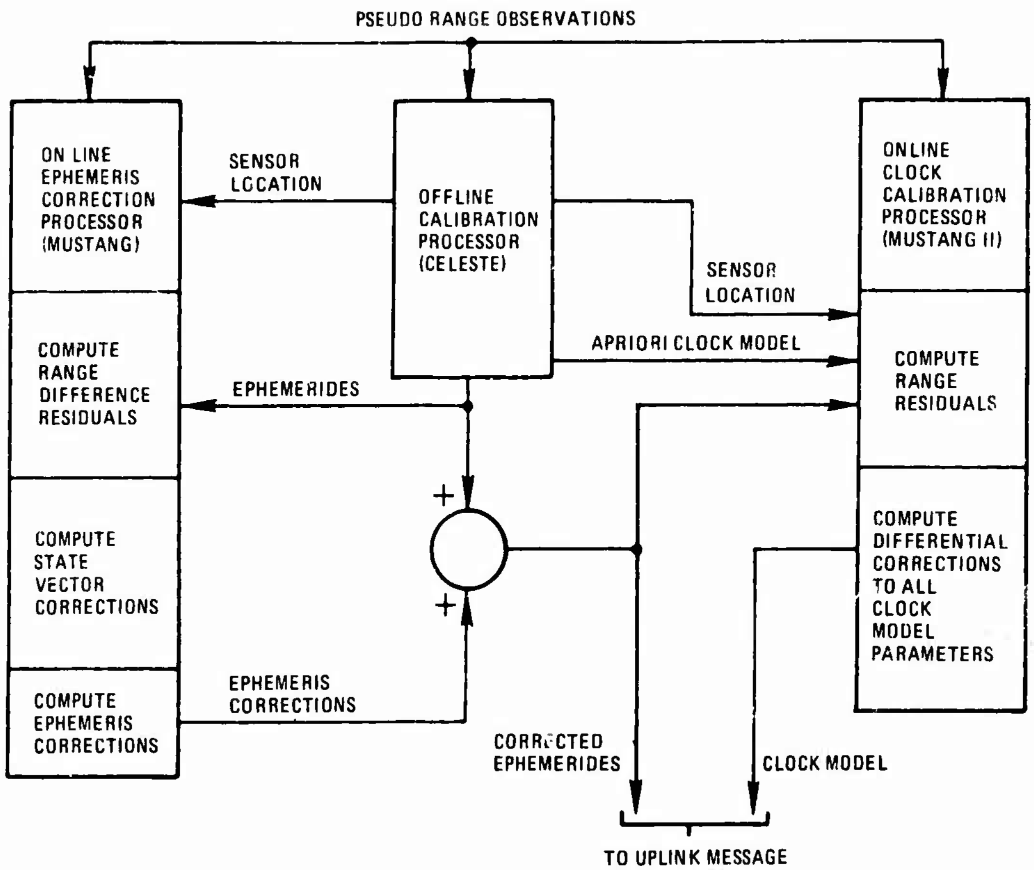

Figure 3-34 MUSTANG Correction Processor

techniques (Kalman, Potter and Andrews Square Root) because of its superior numerical stability with fewer computational penalties.

GPS process noise sources which are accounted for in the software include:

a. geopotential errors

b. station location error

c. radiation pressure

d. clock state noise (for both vehicle and ground clocks)

e. unmodelled in track accelerations

In the determination of GPS clock states, relativistic effects are also included. These corrections account for both the geopotential and solar potential 12 and 24 hour periodic effects on the vehicle and ground station clock rates (frequency).

3.4.3.3 Ephemeris, Clock, and Almanac Prediction. The ephemeris and clock state estimation functions computed an estimate of the position of the satellites and the state of the clocks in the system, at the time of the current observation set. For use on board the satellites, however this data must be predicted forward in time to cover the period of operational usage of the system, ie, as much as 5 days forward from the time of satellites load. Figure 3-35 shows the programs and interfaces involved in this prediction process.

An ephemeris prediction is obtained by applying the state transition matrix of the correction process to the reference ephemeris and the previously computed corrections to these elements. After a prediction has been computed for each 4 minute interval in the orbit, these points are then converted to an earth centered, earth fixed cartesian coordinate system. Each coordinate is successively fit by a sixth degree polynomial in time over an 80 minute span on 60 minute centers to provide nominal one hour fits. The coefficients of these polynomials are tagged with an epoch time and stored in the data base for subsequent assembly into an upload message.

Clock polynomial coefficients are computed by taking the offset and drift terms estimated during the last clock state estimation process, translating these values to equivalent parameters relative to the system time standard and modifying these parameters by the deterministic effects of relativity. (See Part II, Volume A, Report 6, Relativity Analysis.) The final time oriented clock bias function is fit by a first degree polynomial over one hour spans to provide the clock correction coefficients to be included in the upload message.

The acquisition almanac can be generated on a much less frequent basis, typically once every 30 days, but it must also be included in

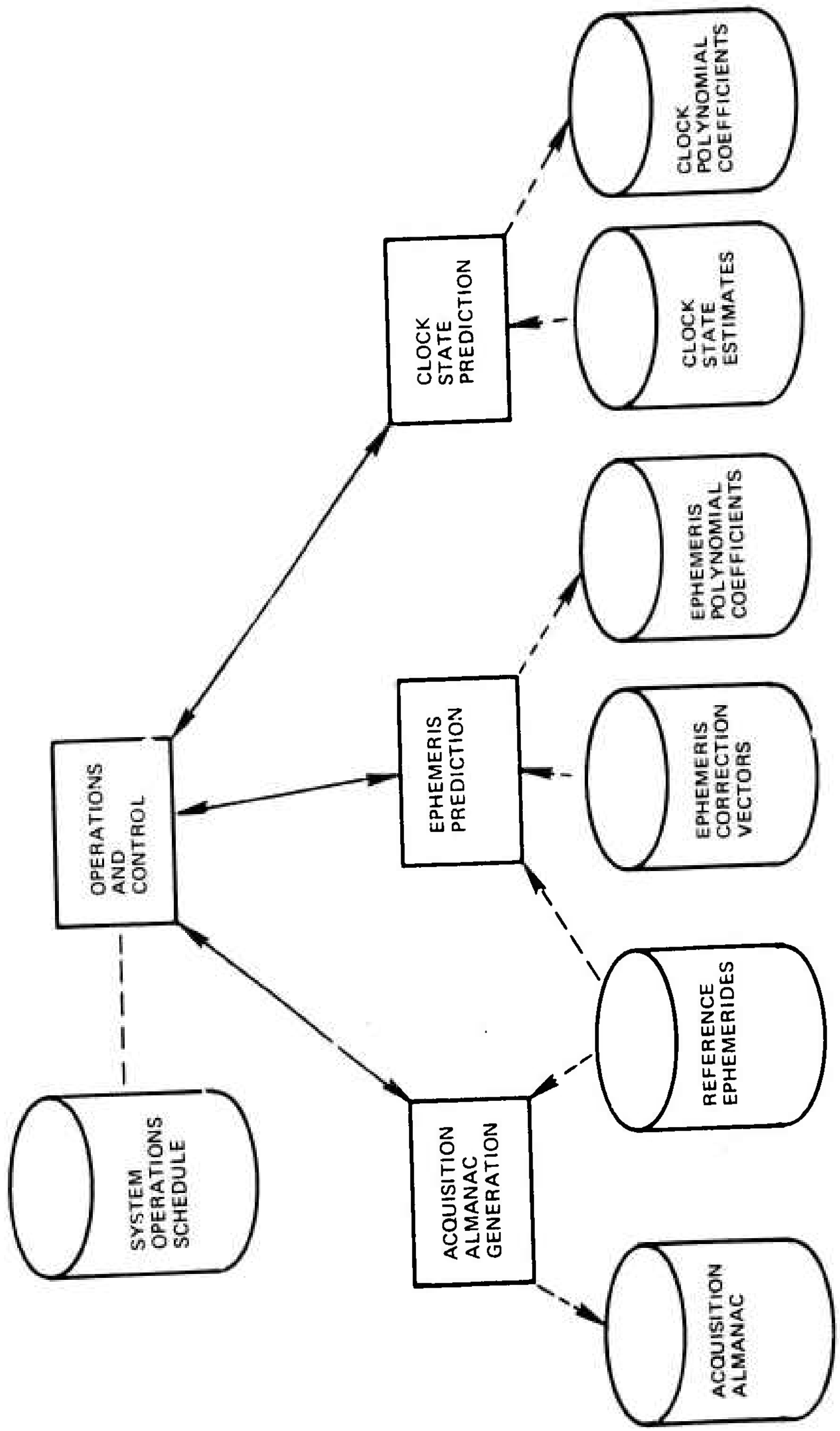

Figure 3-35 Ephemeris, Clock, and Almanac Prediction

the appropriate upload message. Accuracy requirements on the almanac are such that these elemetns can be derived from the reference ephemeris. The classical Keplerian elements will be used in the process.

3.4.3.4 Upload Message Generation and Upload Control. The basic navigation data to be loaded into the satellite vehicles was generated by the programs described in the preceding paragraph. To deliver this data to the satellites, however, it must be formatted into a message compatible with upload and vehicle format requirements, it must be addressed to the proper locations in satellite memory, it must be augmented by error detection/correction data, it must be validated to assure that effective navigation can occur with this data, and it must be efficiently transmitted to the satellites under MCS control. Figure 3-36 shows the programs and interfaces involved in this message generation and uploading process.

Five distinct data types are incorporated into an upload message:

a. Ephemeris Ploynomial Coefficients

b. Clock Polynomial Coefficients

c. Almanac Predictions

d. Clear Commands

e. Navigation Processor Instructions

The first three representing navigation data were discussed in the preceding paragraph and involve data which is stored for later use by the satellites. The clear commands configure the navigation payload, select a new frame length, for example, or adjust the satellite clock. The navigation processor instructions contain data which dictates broadcast frame length, refresh interval, physical storage address, and size of the upload message. Data is to be sent to the satellite on a frame-by-frame basis, each frame being made up of message blocks. Figures 3-37 and 3-38 shows the relationship between the basic command data types, a block, a frame, and an upload message. The message generation program must assembly these basic data types into the appropriate blocks, attach error-detection bits to each block, assembly the blocks into frames with appropriate navigation processor instruction data on the front of each frame (this data identifies the storage location for the first and subsequent blocks, number of blocks in the message and the secure key which guarantees access) and assemble these frames into an upload message for a particular satellite.

To validate this message two separate actions are undertaken. As part of the message generation process the error detection bits in each block are evaluated after generation and subsequent retrieval from the

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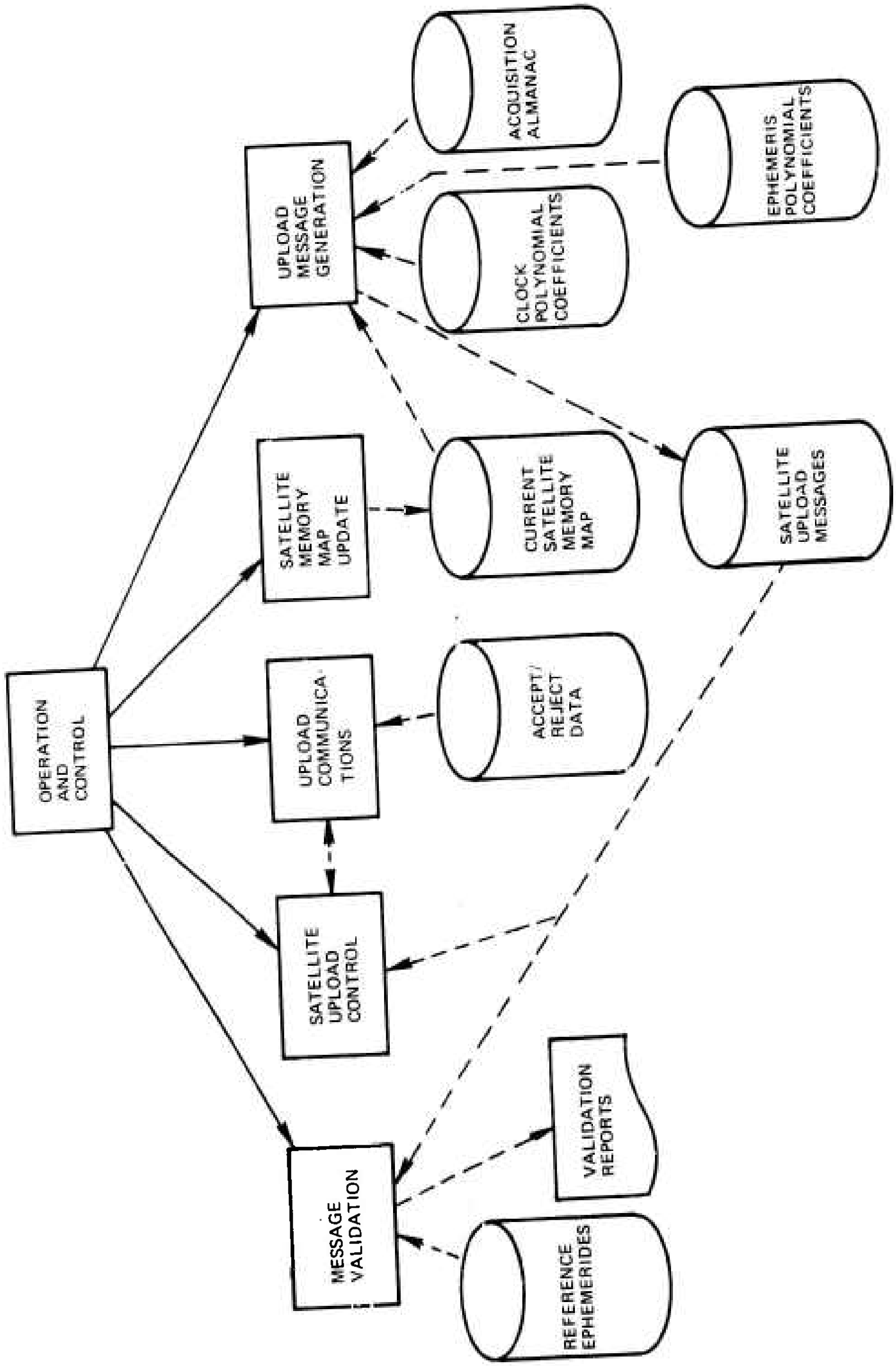


Figure 3-36 Upload Message Generation and Upload Control

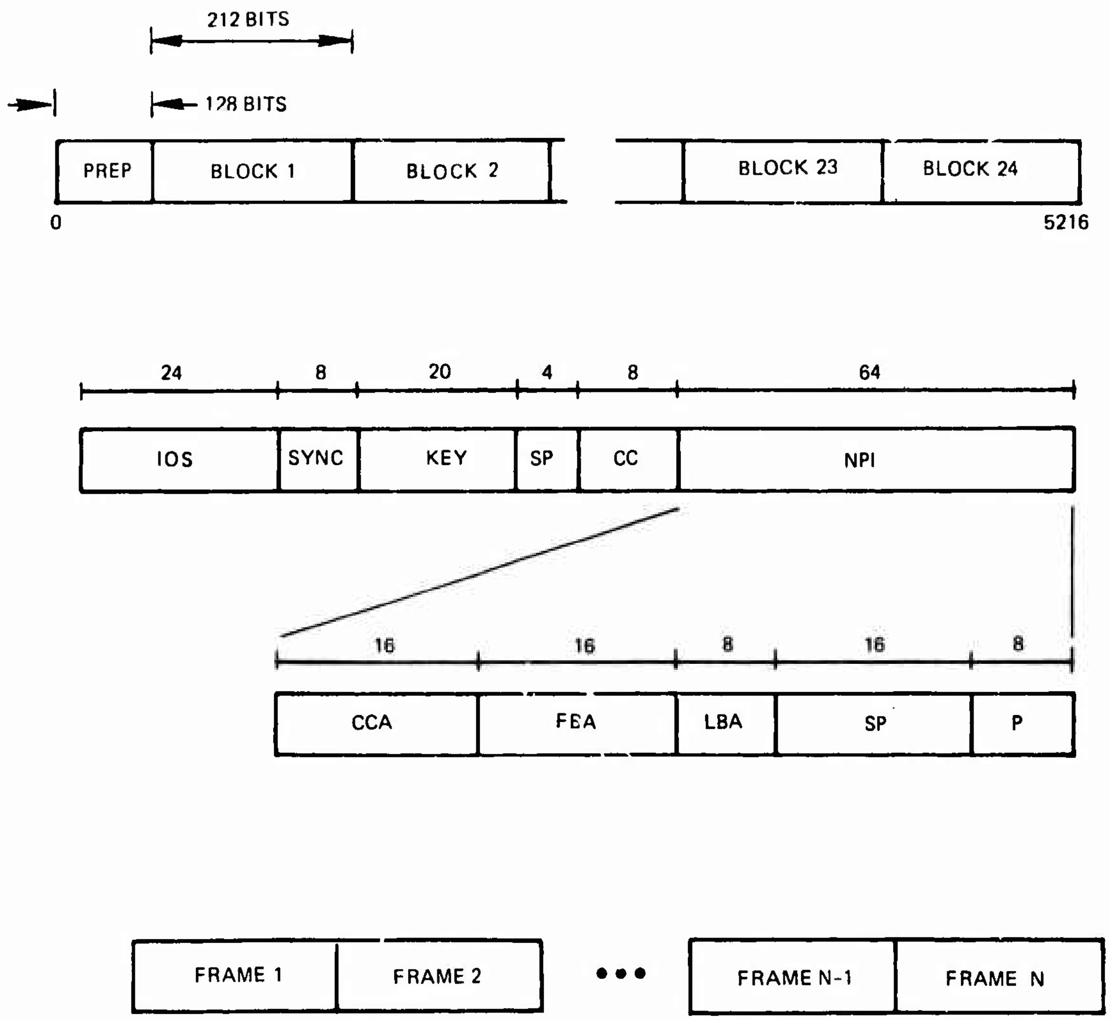
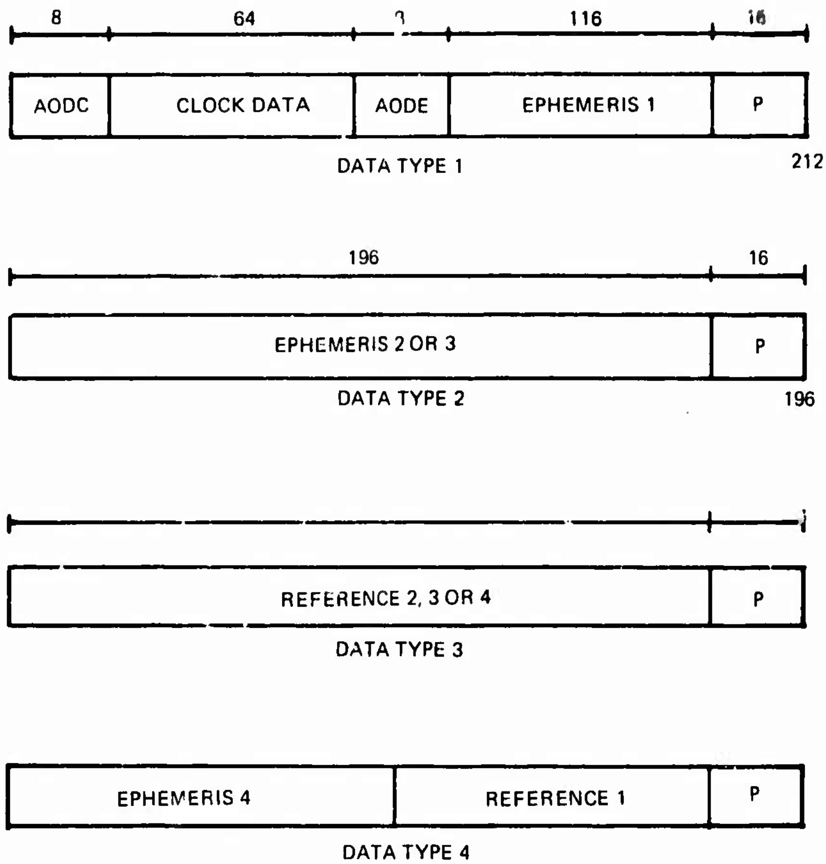


Figure 3-37 Upload Message Structure



AODC – AGE OF CLOCK DATA
AODE – AGE OF EPHEMERIS DATA
EPHEMERIS 1 – PART OF EPHEMERIS COEFFICIENTS
P – PARITY FOR BLOCK

Figure 3-38 Message Block Types

data base, to assure that the subsequent verification of error detection bits will mean suitably low probability of an error in the actual message. The other form of validation requires that the data be used in a simulated navigation. The message validation program accomplishes this function. Figure 3-39 shows a six day timeline indicating a single day's worth of actual pseudorange observations and a six day ephemeris. The first day's ephemeris has been determined by the ephemeris estimation process by processing the pseudorange observations in a differential correction algorithm. The last five days are the predictions which will be uploaded. In generating a message, the message generation process assembles six days worth of ephemeris and clock data, carrying the first day's data for the validation process. The message validation program selects sets of four observations from the first day for the given satellite, computes satellite locations and clock biases from the message data (just as a user or monitor station would), and computes a direct navigation solution. If this solution corresponds to the designated monitor location, within some tolerance, the message is considered valid.

Once the message for a given vehicle has been generated and validated it can be sent to the upload station in preparation for the upload pass. The transmission process is carried out by the MCS communication function under control of the Upload Control program. The Upload Control program provides the MCS operator interface for all control and status functions associated with the vehicle upload process. The MCS operator can accomplish the following from his interactive console:

a. Transmit to the Upload Station on a forward and store basis

- One or more satellite messages
- Upload station schedule

b. Transmit, in real time, control inputs which -

- Cause a loop test
- Enable transmission at a message at the scheduled time
- Cause transmission of a message
- Abort transmission of a message
- Cause retransmission
- Bypass verification or echo checks

c. Transmit, as required, control inputs which set the verification reject level.

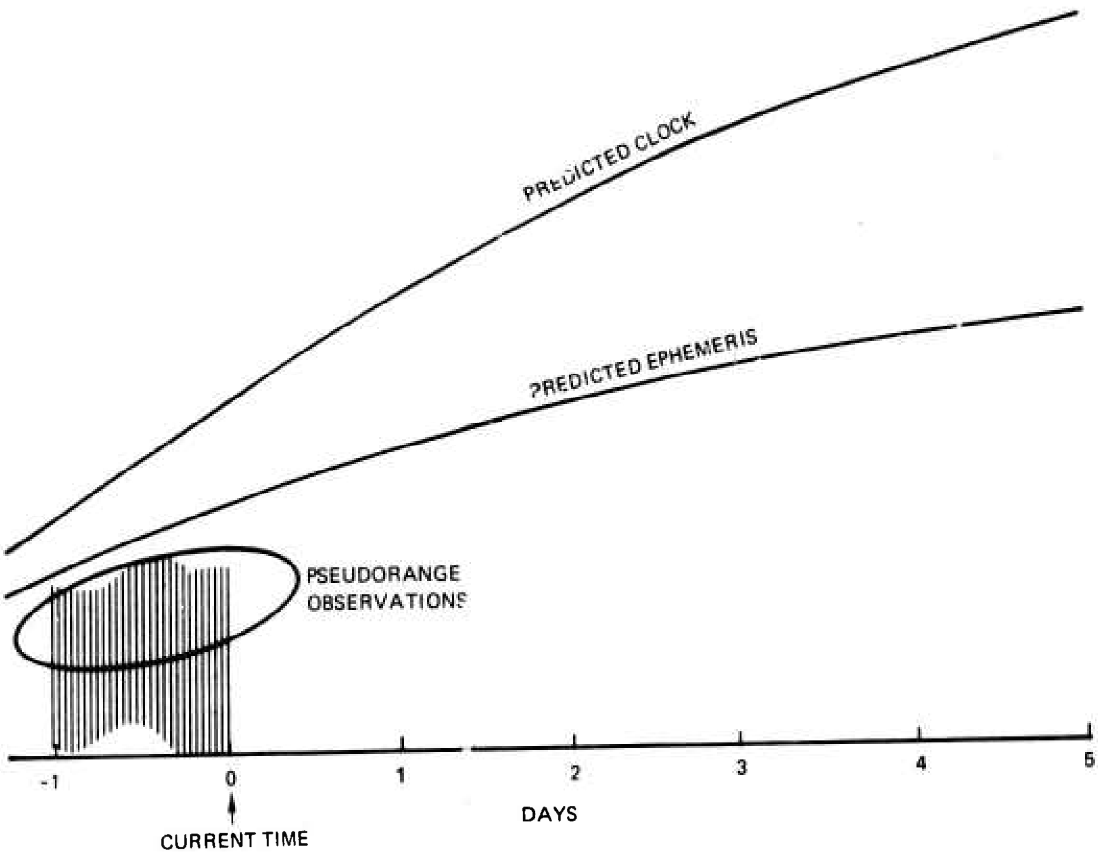


Figure 3-39 Upload Data Schematic

In response to these control actions the Upload Station software provides status messages which the Upload Control program displays to the operational user which identify:

a. Status of station equipment

b. Status of loop checks

c. Status of the upload process during the process

d. Status summary of an upload

After the load process is terminated a status report is generated giving an exact accounting of which upload frames were accepted, which were rejected, and which secure keys were used. This data will be used by the Satellite Memory Image Update program to create an exact map of the contents at the satellite memory, so that under any circumstances the content of the satellite memory is known. This same memory map is used by the Message Generation program to determine where in the satellite memory a load should begin.

3.4.3.5 Status Monitoring. In order to effectively control the GPS system, the operational staff must be continually aware of the status of each of the segments under their control, specifically the control and satellite segments. The status monitoring program has been placed in the MCS software system to format and display the status date collected from the monitor, upload, MCS, and satellite components of the system. Figure 3-40 shows how it interfaces in the software system. It will be executed on an as required basis to display status.

Four specific status displays will be available. A separate display format will be provided for each monitor giving:

a. The status of each replaceable hardware unit at the station

b. A summary of the most recent faults detected and the associated times

c. A summary of the most recent communications with the station and the amount and types of data communicated

d. A summary of the most recent maintenance activities at the station

e. A summary of the most recent diagnostic test run with the station

f. A summary of the pseudoranging and navigation solution residuals for the last day

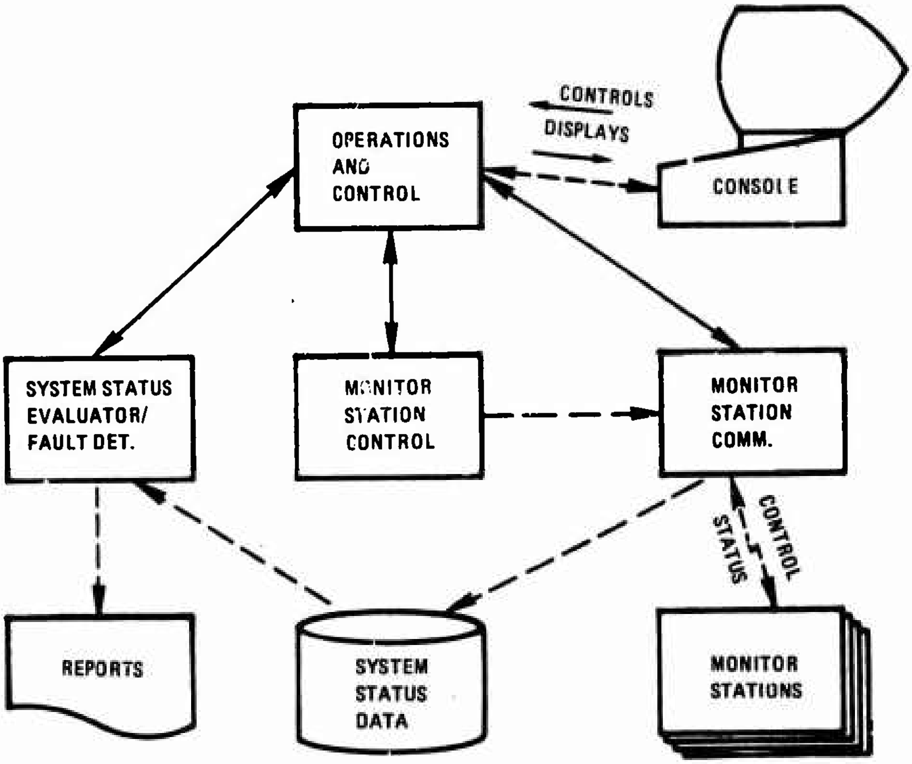


Figure 3-40 System Status Monitoring and Fault Detection

g. A summary of the experienced bit error rate in the L-band downlink

Since the upload station is configured to be a superset of a monitor station, each of the status summaries identified above will also apply to the upload station. In addition, the programs will also provide a summary of the most recently completed upload process for each satellite, giving transmission times, amount of data, load status, and bit error rate.

Since the MCS consists in the main of computer system, communications system, communications equipment and operating personnel, the status of concern is most likely personnel schedules. Thus the MCS status display will respond only to special inputs keyed in by scheduling or operations planning personnel.

Satellite status is affected by both MCS and SCF control. However, the status to be displayed in the MCS will be oriented to the status of the vehicle if it affects the navigation performance of the GPS system specific status displays for each vehicle include the following:

a. Navigation Payload Configuration, as determined by commands from both upload sources. Typical data involves clock adjustment status, transmitter power level, operating processor, secure key status, amount of navigation data available, clock bias, etc.

b. Selected Telemetry Data

c. Summary of Satellite Events such as orbit adjusts, SCF uploads and US uploads.

The satellite related telemetry inputs are supplied by a set of MCS programs, to be developed by the satellite contractor, which retrieve data from the SCF using the MCS communications program. These programs process and format the incoming telemetry data into a suitable display compatible with the status monitoring program.

3.4.3.6 Performance Evaluation. Evaluation of the GPS system operational performance is most effectively accomplished through analysis of the actual navigation performance. This program provides the capability to examine navigation performance experienced at the monitor stations and to evaluate the degradation in this navigation performance caused by imperfect orbit and clock predictions. Figure 3-41 shows the software system interfaces with this program.

Two separate evaluation techniques are used in the system. The software residing at the monitor stations makes navigation solutions at the monitor when 4 satellites are in view. These position fix solutions are compared at the monitor with the known location of the

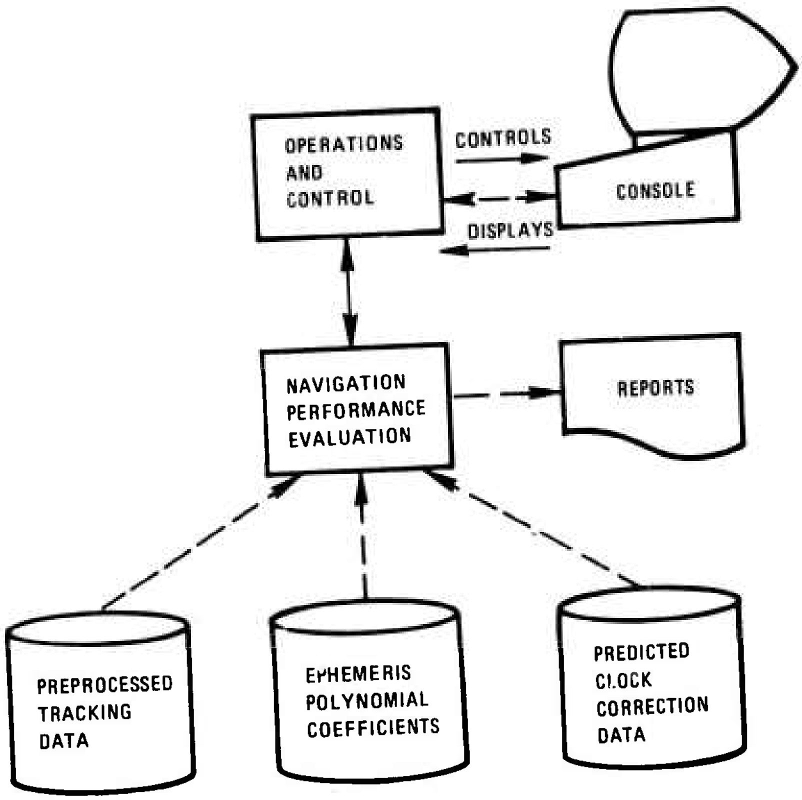


Figure 3-41 Navigation Performance Evaluation

monitor, and when differences larger than a data base defined value exist the solutions are relayed to the MCS.

Separately, the MCS computes navigation solutions for each monitor from the smoothed tracking data available in the MCS. These single point solutions are performed whenever two or more satellites are visible. When four are visible, a full solution vector is obtained. When three are visible, station altitude is substituted, as a known, resulting in a solution for horizontal position and clock bias. When two satellites are visible, altitude and clock bias are solved for, and altitude is compared with known station altitude. In each case, standard deviations in position and clock bias are computed, along with the corresponding GDOP or component of GDOP. If desired, the navigation analyst can delete one or more satellites from the navigation solution process, thus providing a mechanism for evaluating and isolating the contribution of a particular satellite to the solution.

The program will also maintain a continuous estimate of ranging error by computing the difference between the observed pseudoranges and the actual range computed using known station location and estimated satellite location. The clock bias estimated in the navigation solutions identified above will be presented with this data in order to obtain ranging error.

Orbit prediction errors will be evaluated by comparing the actual ephemeris computed for a satellite during an interval of observations, with the orbit data available for that interval during the previous day. Two components of ephemeris error will be presented:

a. The difference between the reference ephemeris and the computed ephemeris

b. The difference between the previously predicted ephemeris in polynomial form and the computed ephemeris. Similarly, clock prediction accuracy evaluations will also be made, comparing today's observations and solution model parameter values with yesterday's prediction of clock parameter variations.

3.4.3.7 System Scheduling. Operations in the GPS system will be guided by the system schedule, nominally generated on a weekly basis. Figure 3-42 identifies the computer programs and data interfaces involved in this process.

The driving force on the system schedule is the satellite ephemerides and the test and operations timelines. The System Schedule program computes the framework for the schedule by determining the following events from the reference ephemeris data:

1. The rise and set time of each satellite at each monitor and upload station.

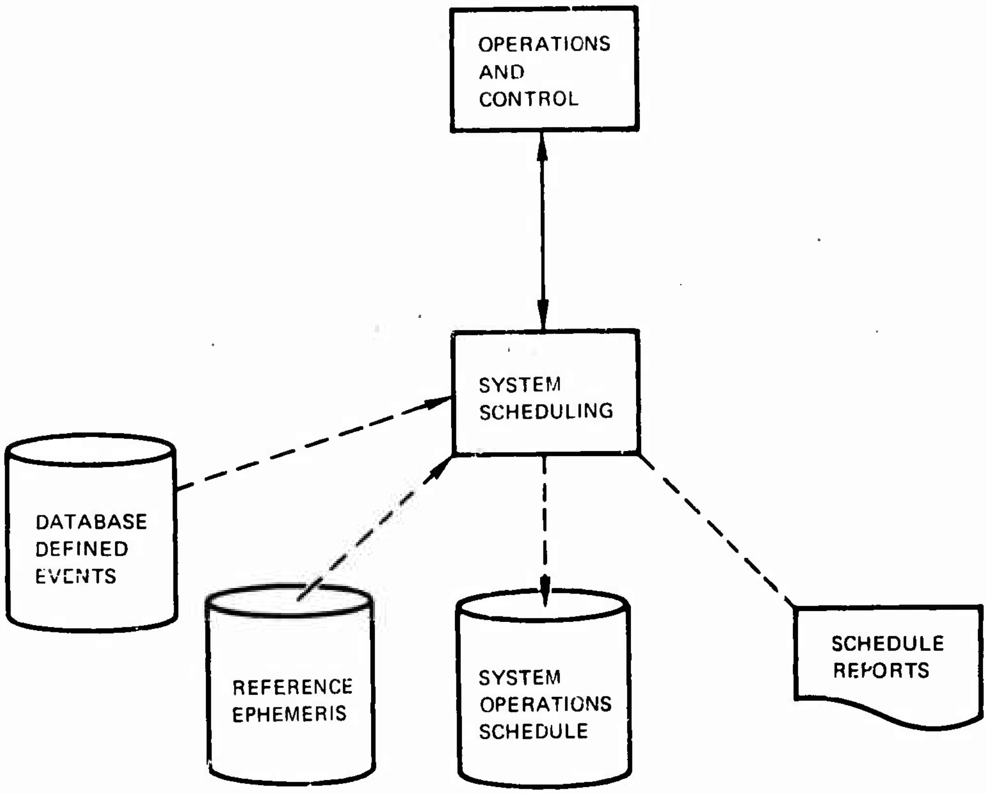


Figure 3-42 System Scheduling

2. The periods of navigation visibility for predefined test locations.

From data base definitions comes the work schedule for the Control Segment Operational Staff. All other system events are either biased to these framework events or are fit in as required. The System Scheduling program provides the capability to define in the data base events with the following characteristics:

a. Event name and description

b. Time bias from a framework event

c. Station association identifier

In the generation of a schedule these events are fit into time slots defined either by their time bias from framework events or based on absolute time. The program provides the operational scheduler the opportunity to inspect and modify this system schedule on interactive basis until an acceptable schedule is available. At that time schedules for each of the stations are generated by the program.

The system and station schedules serve two purposes. On the one hand, they provide the printed roadmap for the operational staff support. On the other hand, they provide a direct link with the MCS, MS, and US computers by allowing automatic execution of program calls specified in a particular station schedule. It can thus be used to periodically execute diagnostics, to initiate and suspend monitor tracking activities, to initiate upload activities, and to cause upload message loading. This linking to an individual station schedule is accomplished via the operations and control function at the respective station.

The navigation visibility capability of the scheduling program also provides a separate output which lists, for a given time period, all the locations of satellites, the number and name of those visible, and the GDOP's available during the visibility period.

3.4.3.8 <u>Operations and Control Function</u>. This function provides executive control for all MCS software activities. In this capacity, it provides control actions based upon stimuli from operator console inputs, from interrupts, and from schedule information. In response to these stimuli the program performs control actions which initiate or terminate one of the major MCS software functions, schedule (or reschedule) one of the MCS software functions, or display operations control information.

The program which provides the stimulus/response action link is logically partitioned into five program subfunctions as listed below:

a. Operator Console Monitor

b. Scheduled Function Monitor

c. Interrupt Monitor

d. Function Initiator/Terminator

e. Dynamic Scheduler

Figure 3-43 presents an overview of these subfunctions in the MCS hardware/software environment.

The operator console monitor accepts, interprets and responds to requests entered through operators staff consoles. These requests will enable operators to:

a. Control the execution of MCS computational program functions

b. Request displays of system control parameters

c. Alter system control parameters

d. Alter the system schedule of operation

Operator requests will be in the form of commands entered via a console keyboard. These commands will be composed of a keyword which identifies the function requested and a list of parameters which provide information required by the function. This may include processing options, time to execute, time span of processing, and similar control information. Where appropriate, default parameter values will be defined, allowing the operator to omit them from his command input.

In GPS Phase II or III it may be desirable to build and catalog sequences of commands which can be executed by entering a single command (with associated parameters) which identifies the command sequence. Expansion of the command system to include this capability will be facilitated by designing the Phase I command system with a separate syntax scan and command execution phase.

The Scheduled function monitor interprets the system schedule file and scheduling requests which have been entered by operations staff members and requests initiation of the requested function at the specified time.

The operating system will process interrupts and build event table entries which provide the nature and source of interrupts. The Interrupt Monitor, in turn, will evaluate these tabular entries and initiate implied processing. This may include:

a. Immediate execution of an interrupt response routine or system function

b. Scheduling of one or more system functions

PHILCO
Philco-Ford Corporation
Western Development Laboratories Division

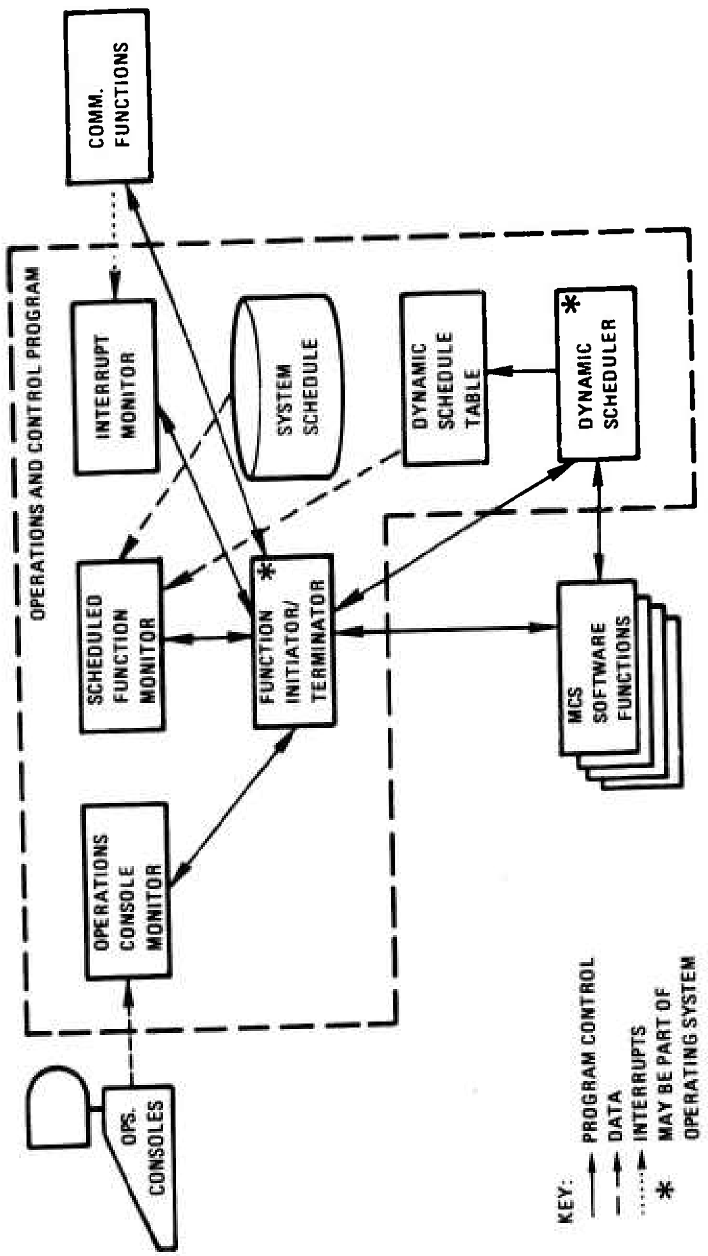


Figure 3-43 MCS Operations and Control Overview

c. Notification of operations staff of occurrence and nature of the interrupt.

3.4.3.9 Operating System Environment. The operating environment in the MCS involves three distinct modes of computer usage:

a. Interactive operation with an operational program in order to provide realtime inputs to a realtime process (such as upload control), or to provide reactive inputs to an operational analysis program doing trend analysis or data fitting where some human instruction in a display/control/display sequence is important.

b. Non interactive (batch) execution of programs designed to perform a given function with no external realtime help.

c. Interactive and batch execution of non operational programs involved with program development, administration, logistics, etc.

Further, there are several operational situations where more than one program must be executing concurrently in order to meet the timing restrictions in the system. Thus, a multiprogramming operating system has been defined as a requirement on the computer system to be selected. Under these conditions it is advantageous, from the point of view of computer utilization, to allow all three modes of program execution to exist concurrently. But restrictions must be placed on the development executions to prevent data or programming errors in one program from affecting the execution of another. Thus some form of memory protection and some form of file protection are mandatory for the system.

The operational data base must also be protected against complete or partial loss of critical system files. The data base dump and restore capabilities will be specified as part of the operating system utilities.

Finally the operating system will be specified to provide an adequate set of supervisory and support programs designed for executing and controlling the performance of application programs. It must perform the following services:

a. Job and Task Management - controlling the definition and execution of operational runs, dispensing the computer resources on a priority basis, managing primary and secondary storage, and reacting to system errors.

b. Data Management - organizing, cataloguing, locating, storing, retrieving and maintaining data.

c. Recovery Management - attempting to recover from malfunctions.

3.4.4 Master Control Station Hardware. The following subparagraphs describe the four major equipment groups which constitute the MCS hardware.

3.4.4.1 MCS Data Processing Equipment Group.

Performance Requirements

The principal function of the MCS data processing equipment is to host the software described in the preceding paragraph. In addition the processing equipment must present compatible input/output ports to its peripherals, to the control and display equipment, to the time standard and to the terminal equipment of the telecommunications network.

Performance Characteristics To support the MS software, the MSC data processor will be a general purpose, scientific minicomputer capable of executing the instruction mix represented by the MS software at a minimum rate of 220,000 instructions per second. In addition, the MCS processor will have a high-speed random access memory with a capacity of at least 64,000 32-bit words. Mass storage will be provided by the incorporation of one or two disc storage units having a combined capacity of 18-million words.

The central processing unit will feature:

a. hardware index registers, arithmetic registers and general-purpose registers all capable of supporting 16-bit and 32-bit operations.

b. a conventional instruction set including load-and-store, arithmetic, logical, shift, data transfer and test-and-branch instructions.

c. double-precision hardware that will provide at least 48 bits of precision in floating point operations.

d. a capability to address all of the random access memory and to direct-address at least 16,000 words.

The processor hardware will incorporate input/output ports for a line printer, a card reader and two magnetic tape transports plus couplers for three CRT terminal/keyboards. The time-of-day interface with the system time standard will accommodate a 30-line parallel input of the System Time Code Word (IRIG B format) containing day of year, hours, minutes and seconds. A 1 PPS interrupt will also be input to indicate an update of the time code word. Status of the time standard will be indicated on three "relay closure" inputs.

To interface with the communications links to the US, RCF and SCF/STC, the processor will incorporate three half duplex, 2000 bps, synchronous interface adapters. Three more identical adapters plus

three auto-dial interface adapters will be provided for connection to the communication links to the MS.

To complete the description of the processor, it will provide for memory protection in the event of power failure. And, it will have a bootstrap program in read-only memory to support an automatic restart.

3.4.4.2 Data Processing Peripheral Equipment Group. The principal functions of the peripheral equipment are to keep records and support software development. To provide these functions the MCS will contain:

a. dual magnetic tape transports, with controller, which will record on one-half inch tape at least 500 bit per inch per track on seven tracks (SCF compatible). Record speed will be 45 inches per second and, typically, the data format will be non-return-to-zero (NRZ).

b. a card reader capable of reading at least 300 80-column punched cards per minute.

c. an impact line-printer capable of printing a minimum of 62 characters in 132 columns at a rate of at least 600 lines per minute.

3.4.4.3 Operations Control Equipment Group. The role of the operations control equipment is to provide a man/machine interface between MCS personnel and the processor. This interface will be established with CRT displays and associated keyboards. The CRT format will provide for the display of 2160 alphanumeric characters in a matrix of 27 lines with 80 characters per line. The display format will be divided into three areas as shown in Figure 3-44. Lines 1-3 are reserved for the display of forced messages, ie., faults, alarms or other system anomalies requring prompt operator attention. Lines 5-25 are used for the display of data called up by the operator. (It is anticipated that the display of Summary Status, Configuration and Performance data will be normally on the CRT unless preempted by the operator). Line 27 is used for the display of keyboard entries. This allows the operator to verify such entries before executing them. In order to provide visual separation between the three CRT areas, lines 4 and 26 will not be used for alphanumeric display. Some typical classes of information displayed on the CRT's are given in Table 3-5.

Figure 3-45 is a block diagram of the MCS processor, its peripherals and the operations control equipment.

3.4.4.4 System Time Standard. The mission of the GPS is to support precision navigation and provide precise time on a world-wide basis. To provide this precise time the GPS must possess a time standard whose accuracy and stability approach those of the standards

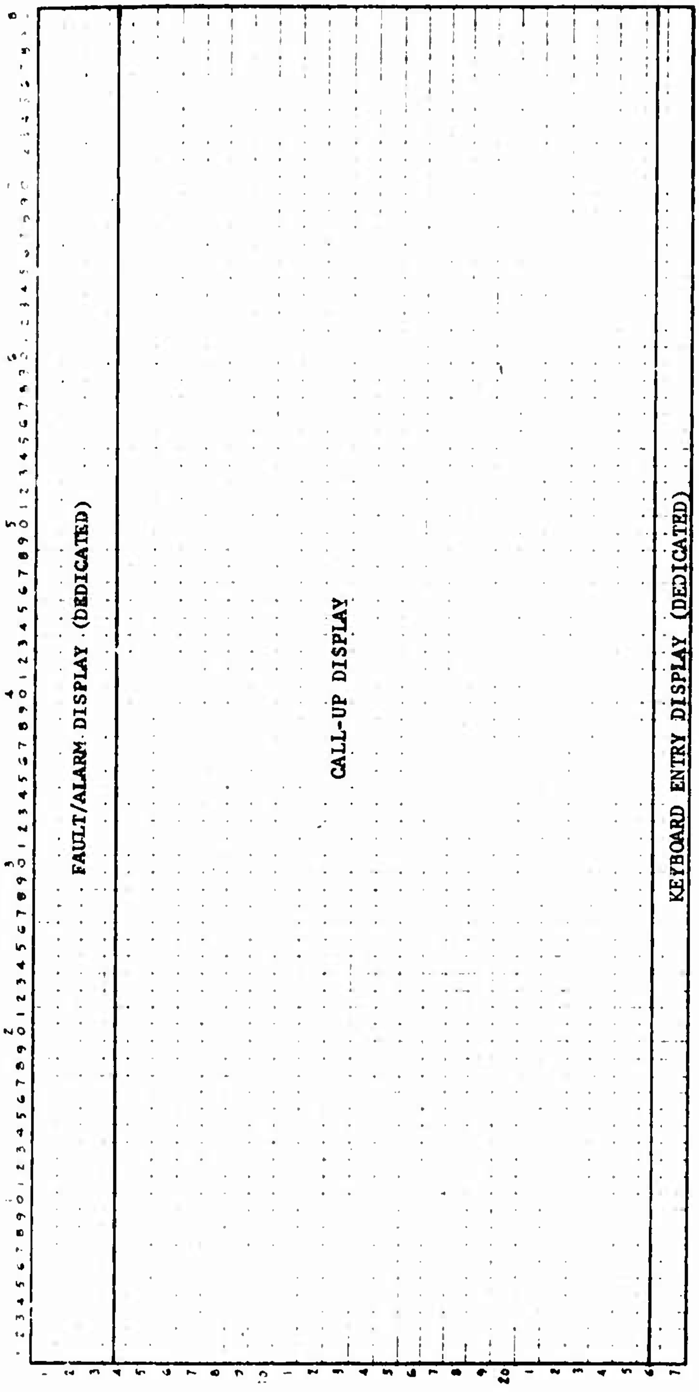


Figure 3-44 CRT Format

TABLE 3-5

ASSIGNMENT OF MCS DISPLAYS

DISPLAY INFORMATION CATEGORY	USED BY:		
	OPERATION CONTROLLER	SYSTEM ANALYST	COMP. TECH/ MAINTAINER
System Time	X	[illegible]	X
Upload Schedule	X	X	X
Status and Configuration:	X	X	X
System Summary	X	X	X
MCS	X		X
ULS	X		
MON	X		
SVS	X	X	
System Performance (Summary performance to be combined w/Summary Status and Configuration.			
EIRP	X	X	
BER	X	X	X
Δ (Sat. position)		X	
Δ (Mon. location)		X	
Clock drift: est		X	
act		X	
Fault Isolation	X	X	X

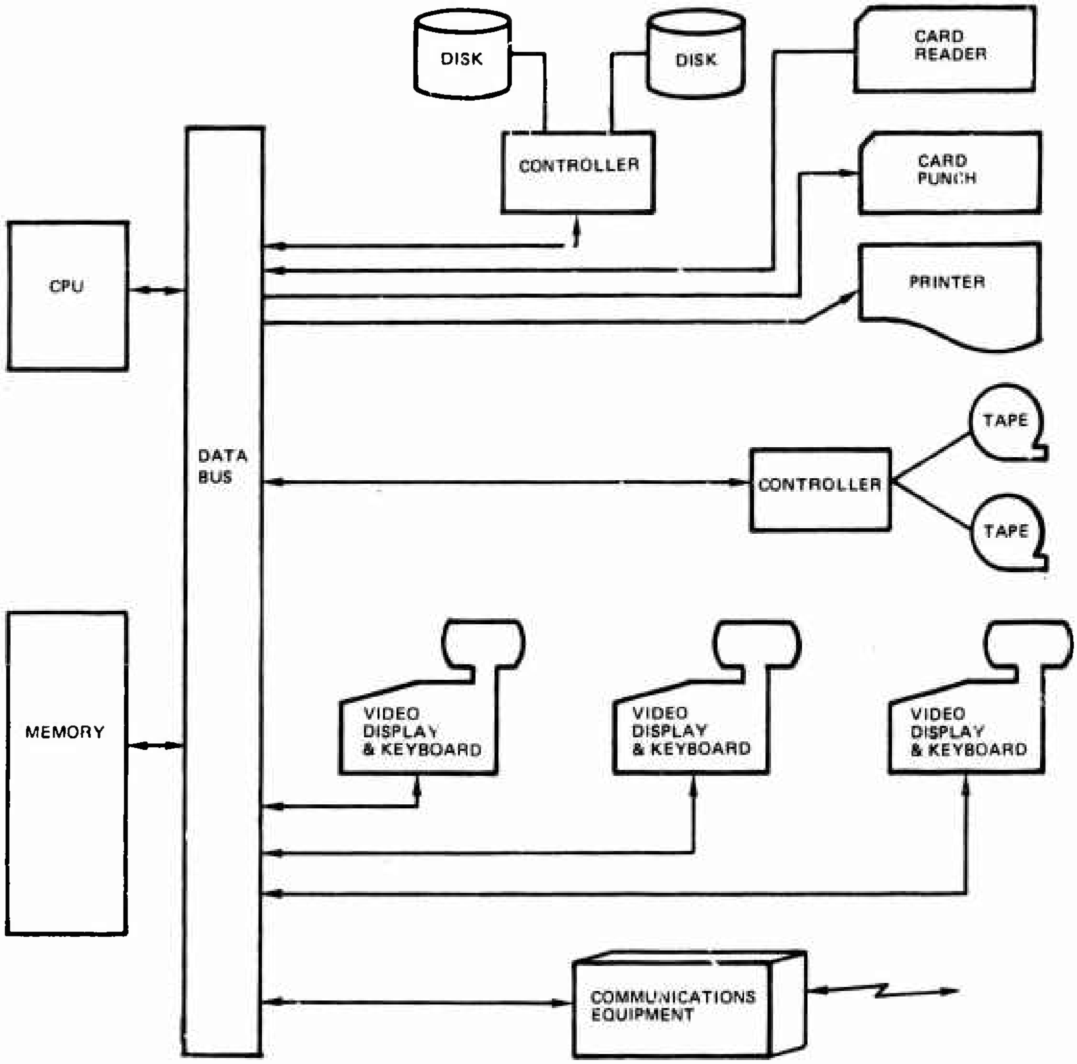


Figure 3-45 MCS Data Processing and Operations Control Equipment Block Diagram

maintained by the National Bureau of Standards (NBS). Given such a standard, its timing output would be provided to a monitor station receiver. Then, that receiver, by definition, would be the "perfect" receiver having no time bias in its pseudorange measurements other than that produced by satellite clock drift. If the clock corrections computed by the MCS software were all made relative to the perfect receiver's clock, the other clocks in the system, specifically the satellite clocks, would all, in turn, be perfect. Perfect time would thereby be available to any user with four satellites simultaneously in view.

In view of the accuracy and stability requirements mentioned above the Hewlett-Packard 5061A Cesium Beam Frequency Standard with option 004 cesium beam tube appears to be the only choice available. The accuracy of the 5061A with 004 tube is $\pm 7 \times 10^{-12}$ sec/sec. The long-term stability over the life of the tube is $\pm 3 \times 10^{-12}$ sec/sec. The short-term stability is as shown in Figure 3-46.

Figure 3-47 shows the 5061A configured into a system providing complete redundancy, automatic switch-over, in case of failure, without interruption of the time signal, back-up power supplies, a VLF receiver for making phase comparisons between the MCS standard(s) and the NBS standards in order to observe any degradation in the performance of the MCS unit.

3.4.5 Configuration/Installation Design of the Master Control Station

This paragraph addresses requirements and standards for the installation of the MCS in Building 22104 at Vandenberg Air Force Base, California.

3.4.5.1 Site Environment. The following environmental conditions prevail at the MCS site:

a. Exterior Conditions. The average yearly exterior conditions are as follows:

• Ambient Temperature	25 deg F minimum; 100 deg F maximum
• Humidity	Up to 100 percent liquid form
• Rain	Precipitation of 1 inch per hour for four hours
• Salt Fog	Sea water in equilibrium with air at a PH of 8.3 and overall salinity of 35 parts per thousand parts of liquid

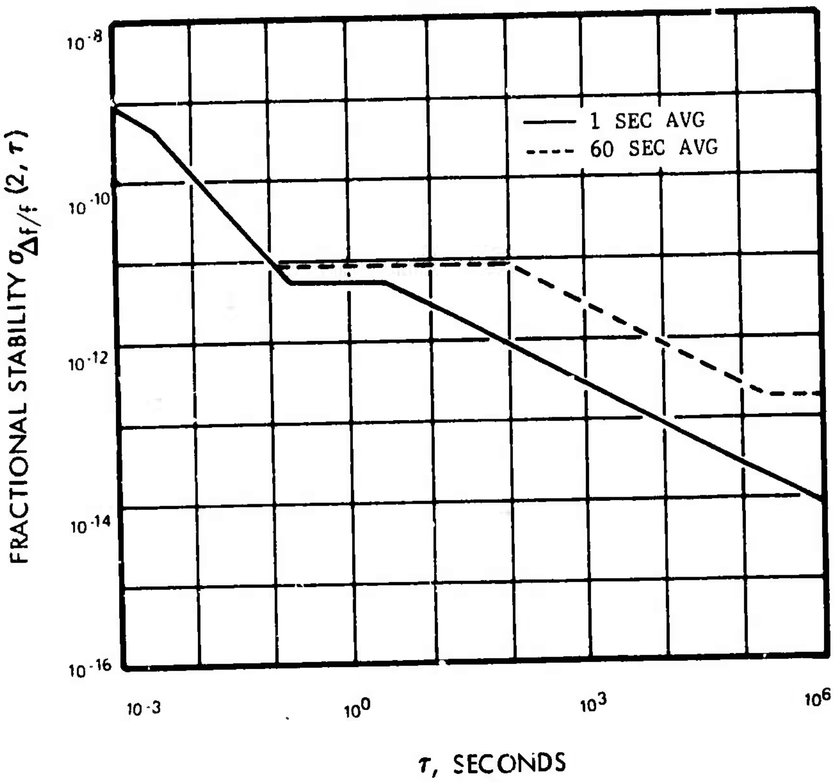


Figure 3-46 MCS Timing Stability

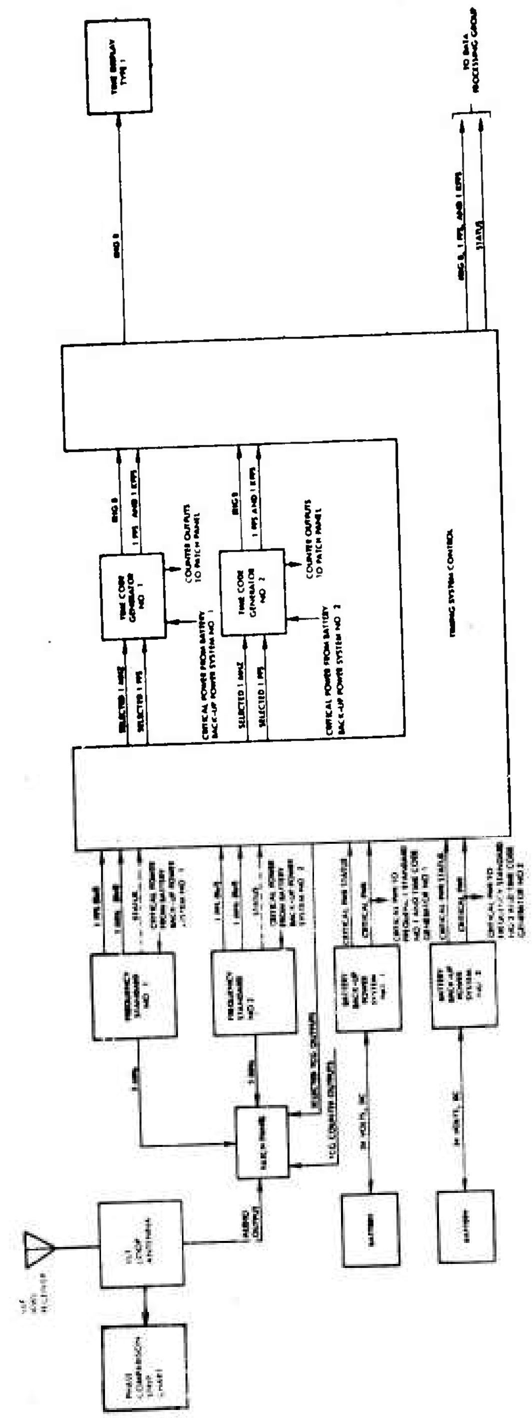


Figure 3-47 Atomic Timing System Functional Block Diagram

•	Blowing sand/dust	Particles of sizes up to 0.30 mon diameter carried by wind blowing at 40 knots at a height of 5 feet.
•	Fungus	Exterior equipment require protection from temperature zone type fungus
•	Solar Radiation	360 Btu/Sq ft/hr for 10 hours per day
•	Seismic	Equivalent to zone 3 per Uniform Building Code of the International Conference of Building Officials.

b. Interior Conditions. The interior spaces are air conditioned as follows:

•	Temperature:	72 deg F dry bulb, ±2 deg F
•	Humidity:	50 ±5 percent

3.4.5.2 Room Arrangement. The MCS will be located in rooms 102, 103 and 104 of building 22104. The three rooms will provide space for the MCS Display Terminals, analysts office, and an equipment rack room. Total space will be approximately 1200 square feet. Air conditioning and necessary fire protection systems will be provided by the existing facilities. The existing main floor plan of building 22104 is shown in Figure 3-48 and a detailed arrangement of MCS equipment is shown in Figure 3-49. The complete area has false flooring of raised panel construction, above a concrete slab. Cable trays run throughout this space. The terminal room is 18 ft x 10 ft in size and provides space for two terminals with operators. Three desks will be provided for the personnel responsible for analysis of data. These desks will be placed in room 104. Pertinent characteristics of the MCS rooms are:

a. Lighting. The technical equipment rooms will be augmented with lighting fixtures to provide an approximate uniform lighting intensity of 100 footcandles measured 30 inches above the floor. In the Display Terminal room the lights over the area containing the terminals will be provided with a wide-range (100:1) dimming control. Lighting on the desks will be a minimum of 100 footcandles. Fixtures and light control louvers, will be located so as not to cast shadows or reflections on the front of the technical equipment. Particular attention will be given to minimizing lighting reflections on displays. Flush-mounted fluorescent lighting fixtures will be provided where required, equipped with integral RF interference filters (General Electric No. 89G635, Sprague IF-37, or equal).

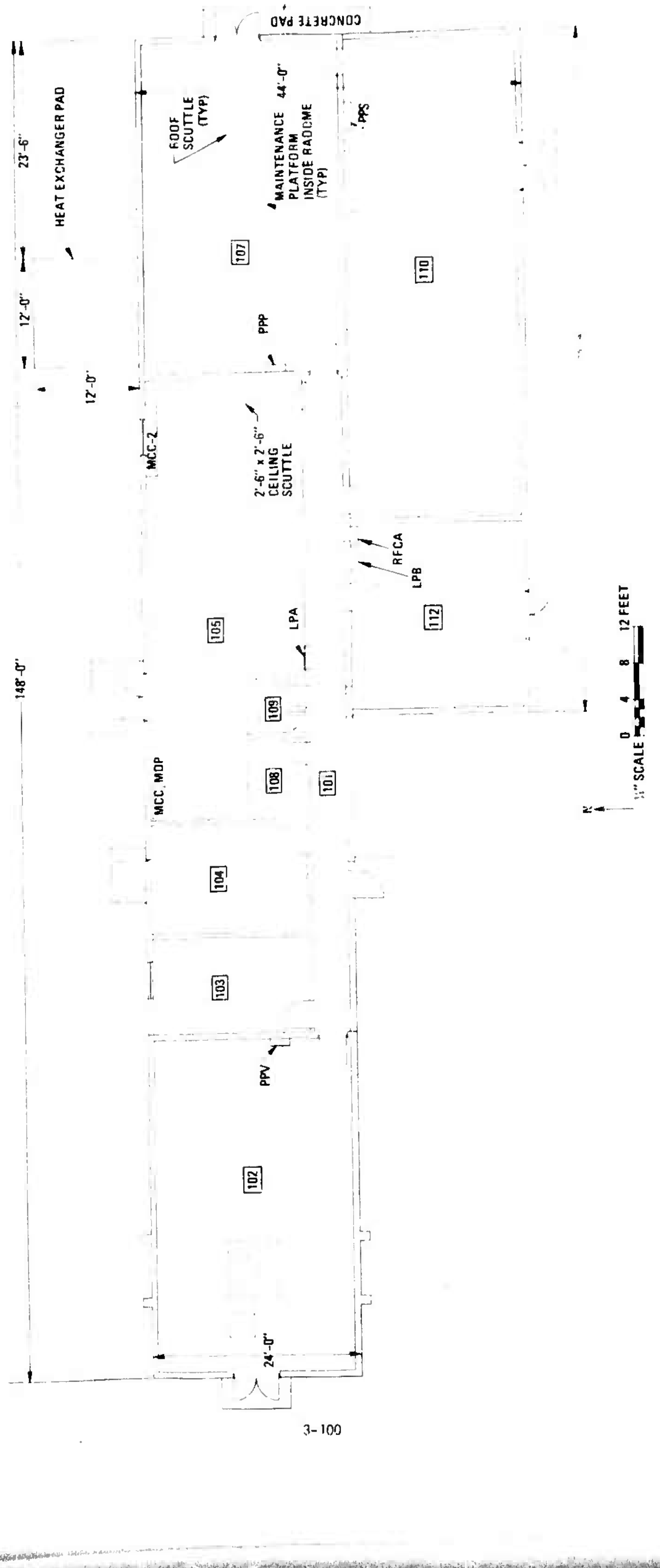


Figure 3-48 Floor Plan (Building 22104)

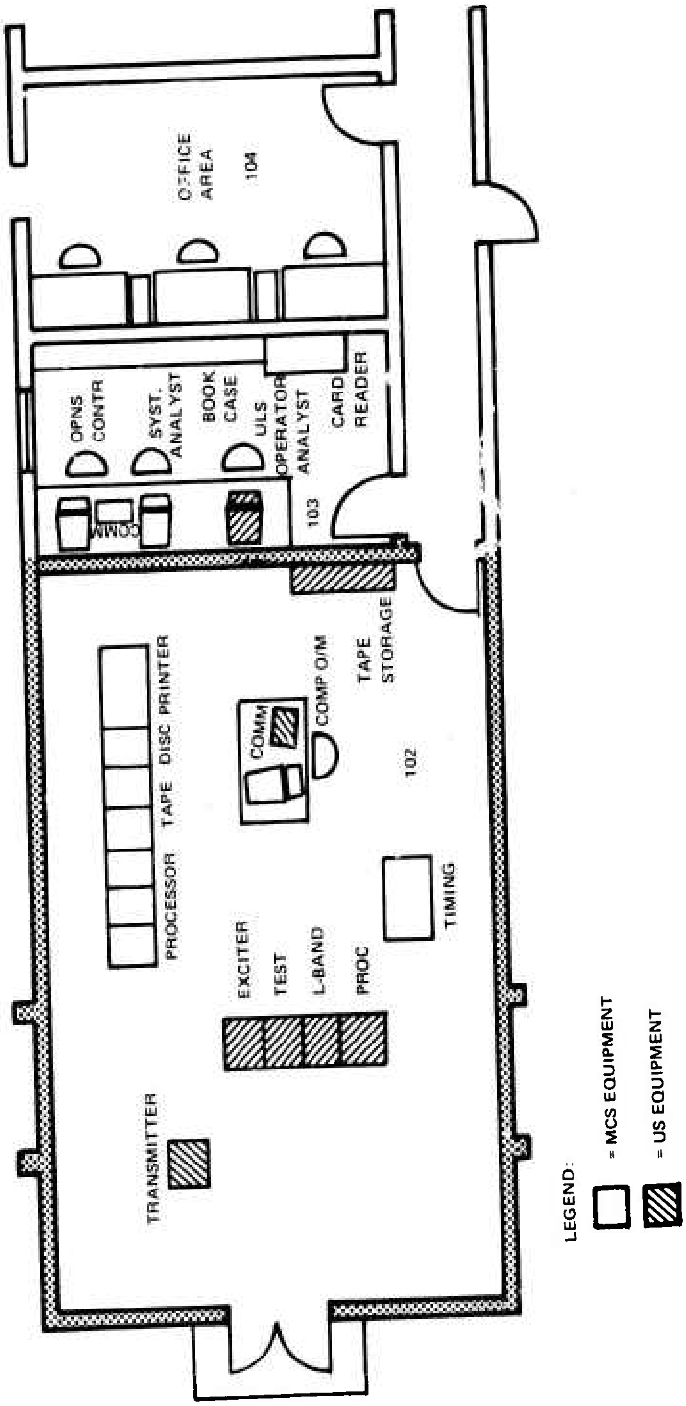


Figure 3-49 Master Control Station Equipment Layout (Vandenberg AF Base - Building 22104)

b. Floors. - Floors in the MCS rooms have a removal panel system meeting the following requirements:

- Panel module size - 24 inches square
- Design loading (uniform load - 250 lb per sq ft)
- Maximum Allowable deflection - 1/300 span
- Height of subfloor above concrete slab (crawl space) - 30 inches
- Panel wearing surface - Plastic laminate
- Panels are interchangeable
- Leveling of raised subfloor - adjustable pedestals

All floor openings will be reinforced as required to preserve floor loading characteristics. All openings will be finished to provide a neat appearance and shall have no rough or sharp edges.

c. Doors. - Single doors into the MCS areas are 3 feet wide by 7 feet high. Extra door height is provided by installation of a one foot removable panel above the door into the existing communications area. Equipment will be moved into the rooms through existing double doors that are 6 feet wide by 8 feet high. The door into the Display terminal area will be modified, if necessary, to minimize sound transmission.

d. Ceilings. - The height of the ceiling throughout the existing technical equipment areas is 8 feet minimum. A continuous acoustical ceiling is supported by suspended tee-bars runners throughout the area. All overhead lighting is flush mounted with the acoutical tile ceiling. Noise levels will be maintained to meet criteria of MIL-STD-1472A, figure 10, for operator areas.

e. Partitions. - The room partitions will be constructed of modular partitions extending from the top of the raised flooring to the bottom of the hung ceiling. Baffels will be installed in the subflooring area to provide plenum chambers for the air conditioning supply system.

f. Convenience Outlets. The technical equipment rooms are provided with duplex convenience outlets of the self-grounding type at approximately 12 feet on centers around the perimeter of each room.

g. Structural. - Room 102 of Building 22104 is constructed of 8 inch thick reinforced concrete walls with 6 inch thick

concrete roofs. The building is designed to support an antenna with radome and to resist 120 knots winds with gusts to 140 knots, and a non-simultaneous zone 3 magnitude seismic load as defined by the National Uniform Building Code. Rooms 103 and 104 have typical stud frame constructed.

3.4.5.3 Rack Arrangement. The MCS equipment consisting of the following major components will be installed in the arrangement shown in Figures 3-50, 3-51 and 3-52.

a. One Processor Rack (22 inches wide x 30 inches deep x 72 inches high)

b. One Disk Rack (22 inches x 30 inches x 72 inches)

c. One Input/Output Rack (22 inches x 30 inches x 72 inches)

d. Two Magnetic Tape Transport Racks (each 22 inches x 30 inches x 72 inches)

e. One Line Printer Unit (48 inches x 25 inches x 46 inches)

f. One table mounted Card Reader Unit (14 inches x 18 inches x 18 inches)

g. Three table mounted display terminals (each 30 inches x 30 inches working space)

h. Two Timing Equipment Racks (each 22 inches x 36 inches x 78 inches).

Cable access to the racks will be through the bottom of the racks. A maximum of 4 inches will be allowed for lateral displacement of racks to avoid cuttings of structural floor members. In no case will such relocation result in restricting personnel traffic patterns or access to equipment. Equipment will be mounted in a manner that will ensure mechanical stability under worst case conditions of equipment chassis slide positioning or anticipated possible seismic loading. Adjacent racks will be fastened together at top and bottom with fronts aligned to within 1/16 inch.

3.4.5.4 Fire Protection.

The following paragraph describes fire protection in the technical equipment room and annunciator panel.

a. Technical Equipment Rooms. - Fire protection for the technical equipment rooms of the technical building will be as follows:

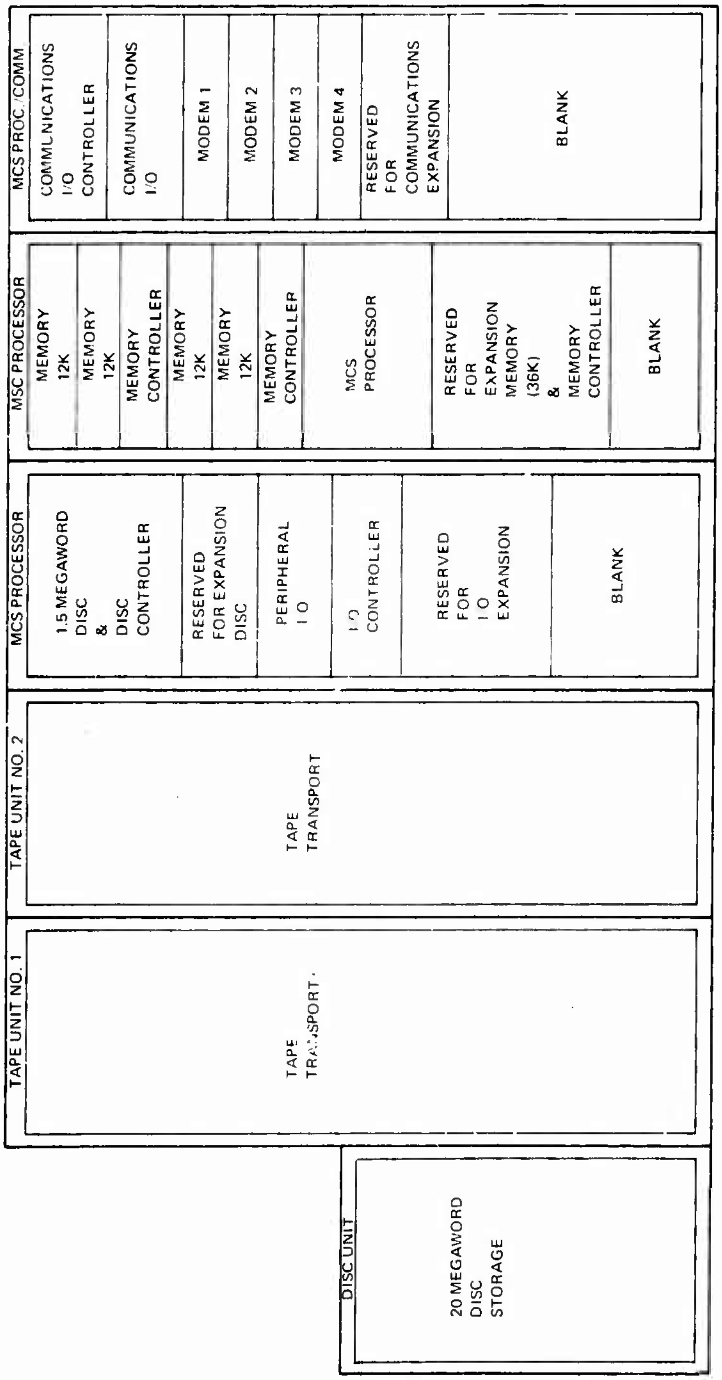


Figure 3-50 MCS Processor Equipment Arrangement

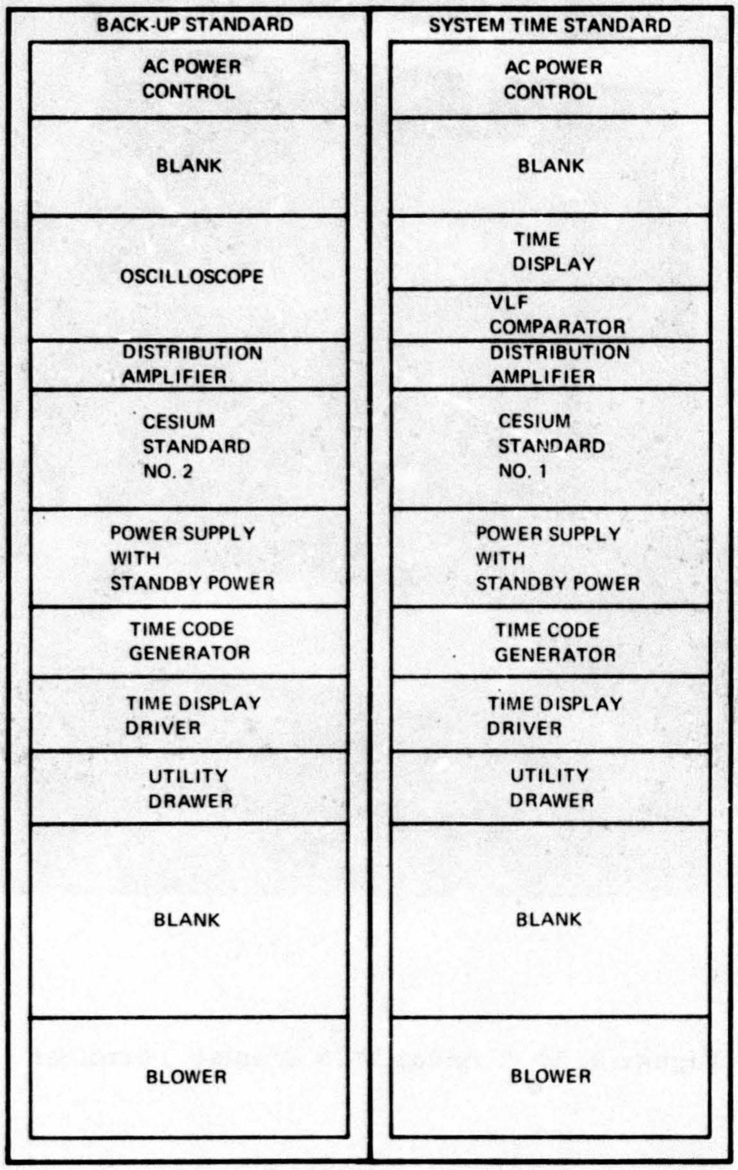


Figure 3-51 MCS Timing Equipment Arrangement

Figure 3-52 Typical MCS Display Terminal

1. Underfloor plenums are provided with ionization-type fire detectors.

2. Technical equipment rooms are provided with ionization-type fire detectors, portable carbon dioxide extinguishers, automatic wet pipe sprinkler system, and water hose cabinets located in the corridor such that any area of any room can be reached.

3. The above ceiling plenum are provided with ionization-type fire detectors and sprinklers.

4. The technical power panels and the air handling units are provided with automatic cutoff devices.

5. Manual fire alarm devices are located at both ends of the building.

b. Annunciator Panel. - A central annunciator panel displaying all alarms and detectors is located in the control room of the power house.

3.4.5.5 Interior Temperature Control. This paragraph addresses heating and air conditioning for the MCS.

a. Air Conditioning Facilities. - The existing air conditioning water chilled type facilities for the Complex will provide a total of 45 tons of refrigeration per hour. The estimated heat dissipation loads from the addition of the MCS is given in Table 3-6. The unit has provided all past requirements encountered by the SCF, and will be adequate to meet the small additional requirements of the MCS (approximately 4 tons/hr). The outside air is filtered for 5 micron or larger particles. Automatic controls provide maintenance of set temperature and humidity conditions throughout the facilities. The primary method of equipment cooling will be by circulation of cooling air in equipment and office areas. Rack blowers will circulate the cool air throughout the racks. The warm air will be exhausted into the room from the rack tops for collection by ceiling level return air registers.

b. Heating System. - The Building 22104 heating is provided by the combination air conditioning and heating facility. A total of 30 kilowatts is available to provide the small winter time heating requirements for personnel comfort throughout the facilities.

TABLE 3-6

ESTIMATED MCS HEAT DISSIPATION LOADS

	Btu/hr
• Processor rack	3400
• Disc rack	6800
• Magnetic Tape racks (2)	6800
• Input/Output Buffer rack	1700
• Printer	3400
• Card Reader	1700
• Display Terminal (3)	5100
• Two timing equipment racks	17000
• Four Men (average dissipation)	2600
TOTAL	50,200

3.4.5.6 Electrical Power Distribution. The Prelort complex which includes building 22104 receives primary 60 Hz, 3 phase AC power from the local utility company, via the Vandenberg Tracking Station (VTS) substation, at 12 kilovolts. The primary power can provide up to 1000 kilowatts, 120/208/480/277 volts, 60 Hz, 3 phase, 4 wire electric power for general distribution to the facilities. The VTS power supply is paralled to an emergency generator driven by a diesel engine that can furnish power to the Prelort area in the event the electric power fails. Ample capacity is available for the estimated 16 kw required for the MCS equipment. Figure 3-53 shows the distribution system and Panel No PPV will provide technical power service for the MCS equipment. The present utilization of panel PPV is shown in Table 3-7. Table 3-8 shows the estimated load requirements. Interface of technical power to facility power will be at the panel. Existing wireways will be utilized as the primary means of power distribution from the panel to the equipment racks. MCS power distribution will comply with the following requirements in order to meet existing Vandenberg Tracking Station standards.

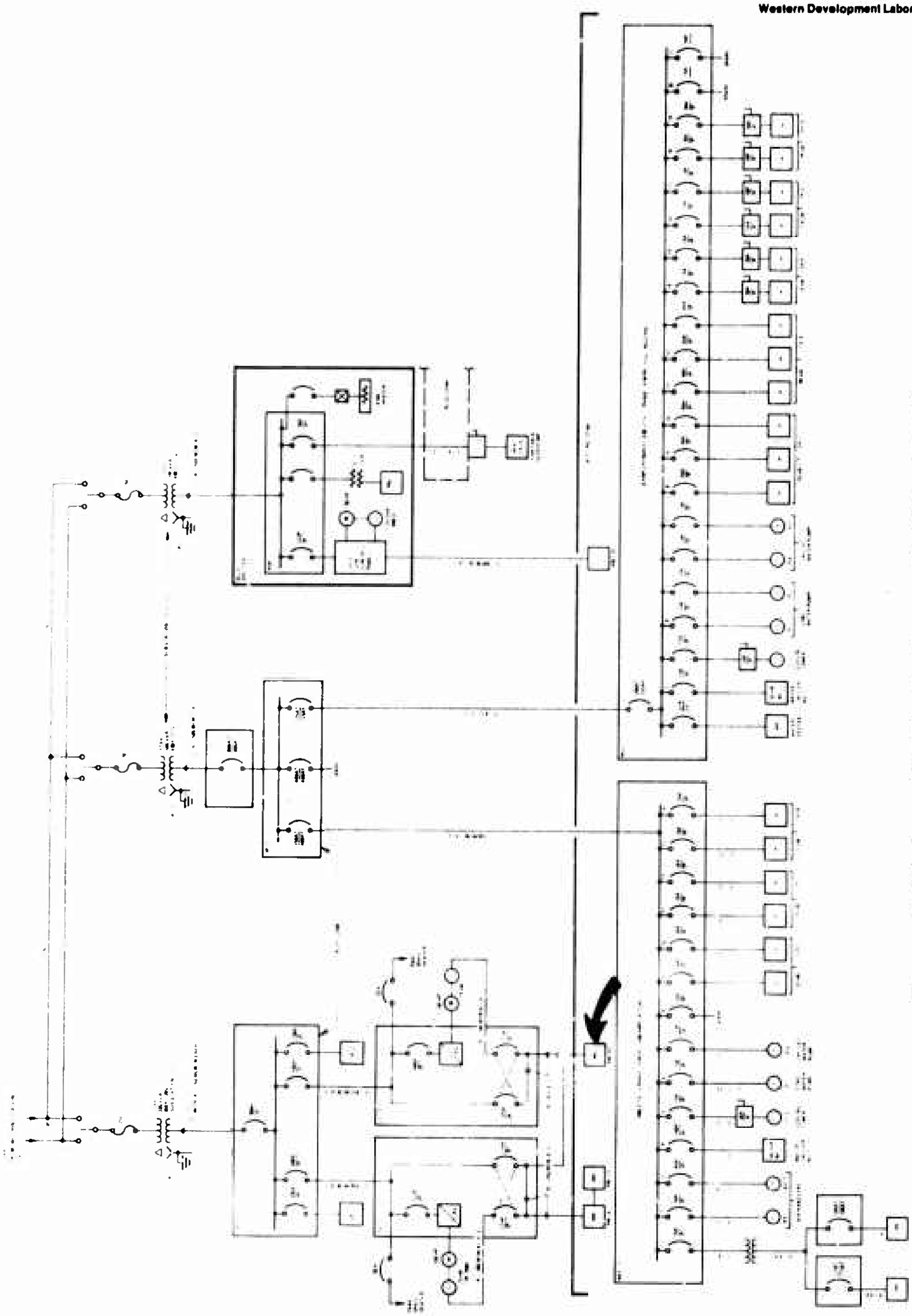


Figure 3-53 Power Distribution System (Building 22104)

TABLE 3-7

POWER PANEL SCHEDULE

PANEL BOARD SCHEDULE

PANEL NO. PPV BLDG. 22104 ROOM 102

MFR ______
TYPE ______
MAIN 225A
120/208 V 3 Ø 4 W

REFERENCE	UNIT NO.	LOAD (KW) ØA	ØB	ØC	MISC	CKT	BKR AMP	BUS CONN	BKR AMP	CKT	MISC	LOAD (KW) ØA	ØB	ØC	UNIT NO.	REFERENCE
SPARE						1	100		100	2						SPARE
						3	100		100	4						
						5	100		100	6						
						7	20		20	8						
						9				10						
						11				12						
						13	20			14						
						15	30		20	16						
						17	30		20	18						
						19	50		50	20						
						21	50		20	22						
						23	20			24						
						25	30			26						
						27	30			28						
						29	20			30						
						31				32						
						33				34						
						35				36						
SPARE						37	20		20	38						SPARE
SPACE						39	-		-	40						SPACE
SPACE						41	-		-	42						SPACE
SUBTOTALS																

POWER
BUS A .0
BUS B .0
BUS C .0
TOTAL 0.0 KW

DISTR. PANEL NO. MDP
BKR. RATING 3P-225A
FEEDER SIZE 4 # 250 MCM

TABLE 3-8
MCS EQUIPMENT ELECTRIC POWER REQUIREMENTS

	EQUIPMENT	Watts
a.	Processor Rack	1000
b.	Disc Rack	2000
c.	I/O Rack	1000
d.	Mag Tape Racks (2)	2000
e.	Line Printer	1000
f.	Card Reader	500
g.	Display Terminals (3)	1500
h.	Timing Eqt Racks (2)	5000
i.	Miscellaneous	2000

	Connected Load Total	16,000 Watts
	Load Factor	90 percent
	Total Power Required	14.4 kW

a. Conduit. - The use of conduit will be limited to applications where power is provided to a single unit or a group of units with a common power input terminal point and where the use of wireway is not practical. Conduit will not be used between wireway sections or runs. Flexible metal conduit will be used for routing of power wiring between wireways and equipment cabinets. The conduit will be electrically isolated from each of the cabinets at the point of entry.

b. Building Wire. - Annealed copper building wire will be used for all wiring runs made in conduit or wireway. Small conductors will be solid wire with Type TW insulation. Conductors larger than #10 AWG will be stranded and fitted with solderless terminal lugs. Conductors larger than #4 AWG will have Type RH-RW insulation. Conductor color coding and allowable current carrying capacity will be as specified in the National building code.

c. Portable Power Cords and Cables. - Portable power cords and cables will not be used as a substitute for fixed wiring. When used in an approved application portable cords will be Type SO and portable cables will be Type W.

d. Outside Power Cables. - Existing power feeders between the substation and the main building are type THW cables in conduit. Power cables within the building are run in cable trays separate from any instrumentation cables.

e. Phase Balancing. - The load currents on each phase of affected power panels will be checked after installation of new equipment to verify that they are balanced within ±10% of the average of the three phases. When the unbalance is found to exceed the allowable deviation, loads will be reconnected, as required, to achieve the desired degree of balance.

3.4.5.7 Ground System. Building 22104 has two separate grounding systems as shown in Figure 3-54 - one covering Room 102 and the second covering Rooms 107 and 110. Each system consists of a grid of 1/8"x2" cooper busbars on 10-foot centers. At each intersection a 12-foot ground rod is driven and brazed to the busbar. The rods are, in addition, interconnected with #4 AWG bare copper cable. The rod grid extends beyond the perimeter of the building. The system for Room 102 includes 25 rods and that for Rooms 107 and 110 includes 48 rods total. Each system is, in turn, tied to the power substation behi·· the building. The ground resistance for the complex is 0.25 ohm, measured during dry weather. No separate facility or utility ground is provided. All items requiring grounding are connected to the grid system. All equipment enclosures shall be connected to the grid using #2/0 AWG insulated cable. These cables shall have a bolted connection to the busbar which is augmented with silver epoxy adhesive. Connection to the enclosure shall be made by a bolted connection to the rack ground stud likewise treated with silver epoxy.

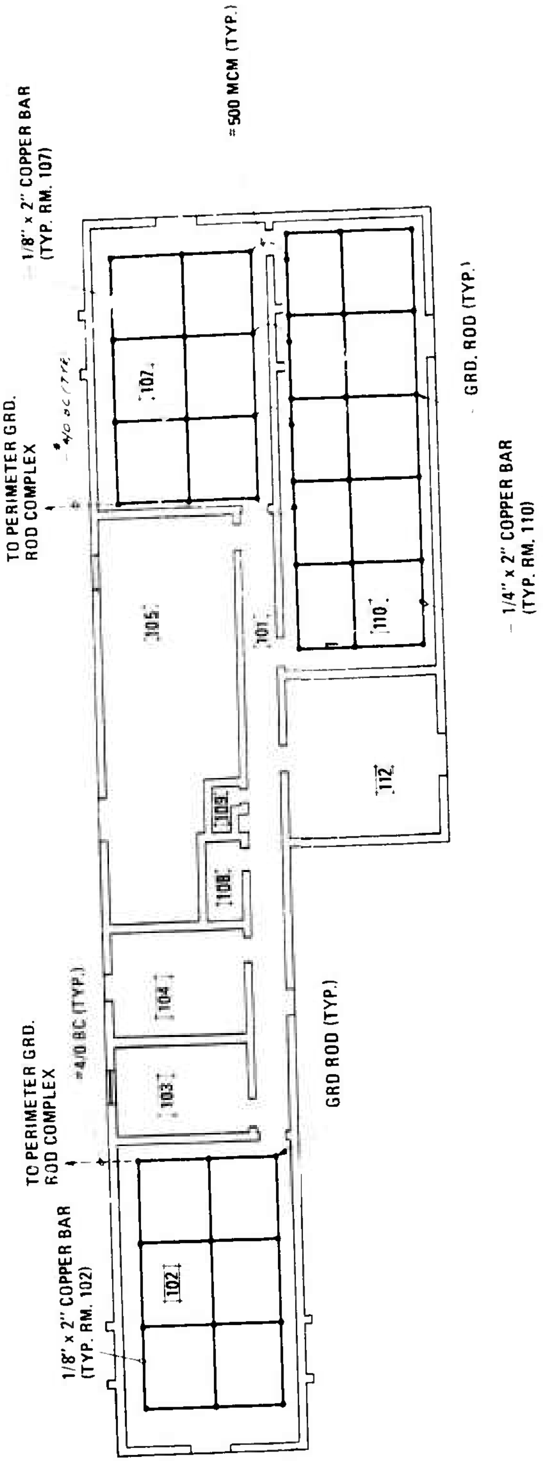


Figure 3-54 Technical Ground System Plan (Building 22104)

3.4.5.8 Instrumentation Cabling. Inter-rack cable assemblies will be standardized to the maximum degree possible. Mixing of conductor types, complexes and conductor sizes will be limited to special applications. Shielding of individual complexes will be accomplished and where used the complex shields will be grounded at the "sending end" only unless special equipment design consideration dictates otherwise. Provision of overall shields on those cables not having individually shielded complexes will be accomplished. All spare conductors will be terminated (if possible) at both ends of a cable. Specifically, the following cabling practices will be followed:

a. Splices. - Normally, lengths of cable will be continuous and without splices between termination points. However, on runs in excess of 1000 ft cables may be spliced as required. Splices will be waterproof and continue all electrical and mechanical characteristics of the cable. Shields will be carried through splices. Color code and complex integrity will be maintained.

b. Cable Number Assignment. - Cable numbers will be accomplished in accordance with the contractor standards. Intra-rack cables and cables between units of a single subsystem will be assigned cable numbers consisting of one alpha character followed by a four-digit numeral. Inter-subsystem cables (except when routed between units of a single rack) and cables routed between station termination cabinets will be assigned five-digit numeric cable numbers.

c. Cable Marking. - Each cables and each conductor within a cable will be identified by number and letter letter combinations using permanently attached markers. Cables will be marked at both ends, at entrances to manholes and at bends. Cables equipped with connectors will also be marked with information identifying the receptacle with which the connector mates. Conductor markers will be a non-conductive material and will identify both the conductor and cable. Conductor markers are not required at cable ends equipped with a connector and backshell.

d. Cable Routing. - Cables between equipment cabinets and from one location to another will follow trenches, and cable trays in false floor areas laid parallel to the room walls and tied to form compact bundles. The cable trays will present a neat appearance and free from sharp bends and kinks. When possible, cables carrying high level (greater than one volt) and low level (one volt or less) signals will be separately grouped and laid with a minimum separation of 4 inches between the groups.

Overhead routing of cables shall be minimized. Overhead cables will be routed in conduits, wireways, or cable trays. In areas with suspended ceiling, cables will be routed above the ceiling unless otherwise prohibited by special

requirements. Conduits, wireways, and cable trays will be suspended from building structural members and be electrically insulated from the equipment cabinets. The existing cable tray arrangement for building 22104 is shown in Figure 3-55.

e. Floor Openings. - Floor cable entrance openings will be cut through the raised panel floor and permanently lined using suitable materials which will provide a cable entrance surface free of sharp edges. When a conductive liner material is used, care will be exercised to ensure that the equipment cabinet is not grounded by the liner. After cables are installed, cable entrance openings will be provided with dust-tight seals of easily removable material.

f. Terminations. - Cable will normally terminate at connectors, barrier strips or taper pin blocks. Cables will be fanned out and formed to match the connecting terminals. Terminal lugs and taper pins will provide insulation support. Crimp type terminals will not be used with solid conductors unless specified by manufacturer. At barrier strips and taper pin blocks, spare conductors not terminated will be cut to maximum length and laced into the bundle with the terminated conductors. At connectors, any spare conductors remaining after all connector pins are filled will be cut back.

g. Cable Ducts. - When installing cables in ducts, care will be exercised to avoid damage or twisting of cables. A pull wire will be installed with the cable and left for future use. After cables have been installed into building cable vaults, ducts will be sealed with a waterproof compound to prevent seepage of water into the building.

h. Secure Cable Plant. - Cables carrying secure signals shall meet the requirements of DCAC 300-175-1, DCA Red/Black Engineering Installation Criteria.

i. Cable Termination Cabinets. - Cable termination cabinets (CTCs) will serve as junction points for interfacing of inter-subsystem and intra-subsystem cables. Each inter-building instrumentation cable will terminate at a CTC. Intra-building cables will terminate at a CTC only when required to achieve the proper cable interface.

3.5 UPLOAD STATION DESCRIPTION

This subsection presents the hardware and software baseline configuration for the GPS upload station. The US configuration developed for this SAR demonstrates, analytically, that it can satisfy all the CS requirements allocated to it. It uses, however, none of the SGLS equipment standing idle at Vandenberg and for that reason may not be the most cost-effective approach to implementing the upload

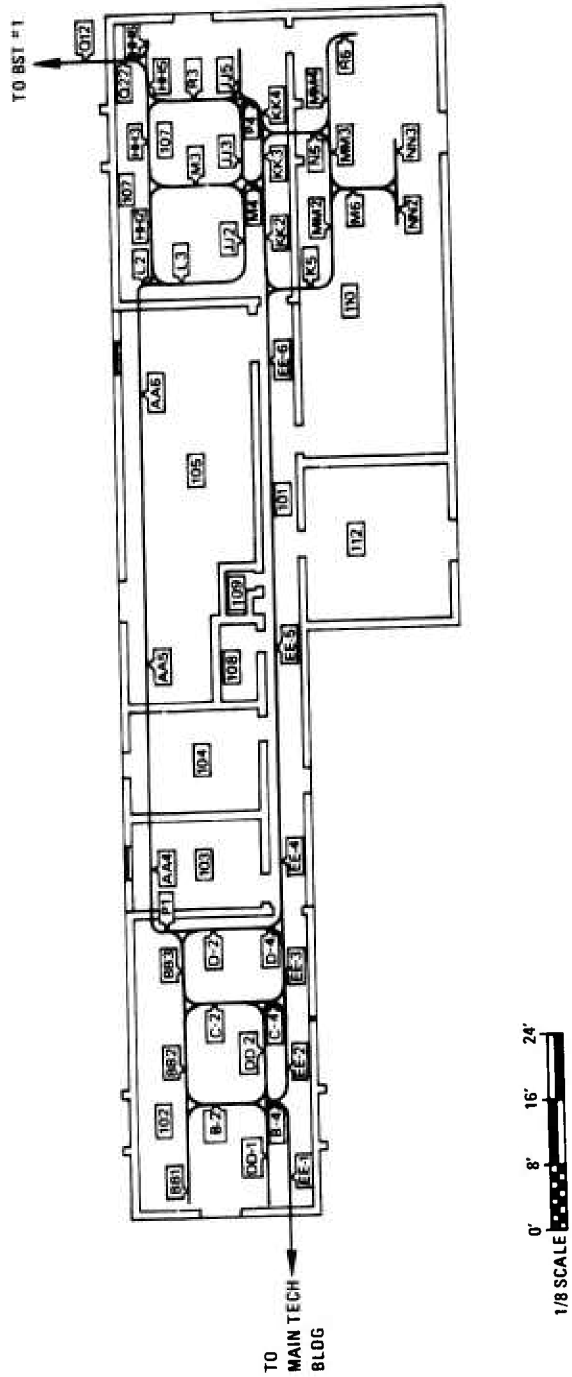


Figure 3-55 Cable Tray Arrangement (Building 22104)

functions. The US instead uses all new equipment because 1) the availability of the SGLS equipment is unknown and 2) the SGLS equipment at Vandenberg -- especially the 10 kW transmitter -- is not truly transportable. However, transportability is a design goal for the US equipment since it may at some future time be relocated away from Vandenberg. Hence, it is recognized that the US baseline configuration could change to incorporate existing SGLS equipment -- nothing in the present baseline design would preclude such a change.

3.5.1 Upload Station Requirements

As its name implies, the principal function of the upload station is to upload the GPS space vehicles, ie, transmit data, provided by the MCS, to the vehicles in order to refresh the data base stored in each vehicle's navigation subsystem. In Section 2, however, a number of ancillary functions are allocated to the US in addition to its prime upload function. Moreover, the US is also allocated specific interface and availability requirements.

The functional requirements to be satisfied by US hardware and software are summarized in Table 3-9. Referring to the table one notes that the US is allocated all the "navigation subsystem control" functions, ie, all the upload functions. Moreover, the US is allocated all the functions of a monitor station. The unique upload functions are: controlling the upload process, validating the upload message, transmitting the upload message and verifying the upload message (including retransmission if verification is not achieved). Each of these functions is discussed below followed by a review of the US interface and availability requirements.

3.5.1.1 Upload Process Control. The US will, as a backup to the MCS, be capable of autonomously controlling the entire upload process of validation, transmission and verification. The US software will acquire and store the upload messages from the MCS, select the space vehicle to be uploaded, point the antenna at the selected vehicle, initiate and monitor transmission, control verification/retransmission and generate the verification message. To support effective upload message transmission the US hardware/software will be capable of directing the US S-band antenna toward a space-vehicle with a pointing (circular) error not exceeding 0.1 degrees.

3.5.1.2 Upload Message Validation. The US will acquire upload messages from the MCS and then will validate these messages prior to transmitting them to the space vehicles. This validation will be performed by a software simulation, of the SV processor and processing algorithms, resident in the US software. This simulation will be capable of reformatting the upload message into navigation data and then validating the quality of this data.

TABLE 3-9
ALLOCATION OF CS FUNCTIONAL REQUIREMENTS TO THE UPLOAD STATION

FUNCTION	Master Control Station			Upload Station			Monitor Station			Tele Com
	HARDWARE CI NO. 237273	SOFTWARE CPCI NO. 237309	PERSONNEL	HARDWARE CI NO. 237277	SOFTWARE CPCI NO. 237313	PERSONNEL	HARDWARE CI NO. 237275	SOFTWARE CPCI NO. 237311	PERSONNEL	CI NO. 237279
Control Segment Operations										
• Segment Initialization and Recovery		X	X			X				
• System Scheduling		X	X							
• Communications Function		X	X		X			X		X
• Display and Control Function	X	X		X	X		X	X		
• Status Monitoring Function	X	X	X	X	X	X	X	X		
Navigation Data Collection										
• System Calibration Data		X								
• Space Vehicle Tracking Data				X	X		X	X		
• System Time Standard	X	X								
• Space Vehicle Health and Status Data		X								
• Space Vehicle Access Key		X								
Navigation Data Processing										
• Tracking Data Preprocessing		X								
• Reference Ephemeris Generation		X								
• SV Ephemeris Prediction		X								
• SV Clock Prediction		X								
• Almanac Data Generation		X								
• Upload Message Generation		X								
Space Vehicle Navigation Subsystem Control										
• Navigation Upload Control		X	X		X	X				
• Upload Message Validation		X			X					
• Upload Message Transmission				X	X					
• Upload Verification and Retry				X	X					
System Test/Calibration/Maintenance										
• Control Segment Calibration				X		X	X		X	
• Ionospheric Data Collection		X								
• Navigation Performance Evaluation		X			X			X		
• Space Vehicle Signal Quality Monitoring				X	X					
• Support Software Development	X	X								
• Segment Readiness Testing	X	X		X	X		X	X		
• Segment Evaluation Testing	X	X	X	X	X		X	X		
• Logistics Support			X							

3.5.1.3 Upload Message Transmission. The US will establish an S-band uplink interface with the space vehicle(s). US hardware/software will provide the following uplink characteristics:

Data rate	1 kbps
Data format	SGLS-compatible
RF carrier frequency	1.75 to 1.85 GHz
Modulation index	1 radian
EIRP	+88 dBm, minimum

3.5.1.4 Upload Message Verification. The US will provide upload message verification in order to maintain the probability of an upload error below 1 x 10^{-15}. Such verification will be accomplished by establishing an L-band downlink with the space vehicle(s). The US shall thereby receive L-band signals from the SVs, demodulate navigation data from these signals and extract the "accept-reject" words from the data. If an SV has rejected a block of upload data, the US will initiate retransmission of the rejected block. The US will, in addition, prepare and store a verification message to be forwarded, periodically, to the MCS.

3.5.1.5 Interface Requirements. To implement its upload functions, the US must establish an S-band uplink and an L-band downlink with the space vehicles. The downlink requirements duplicate those levied on a monitor station. The important uplink requirements are stated above in paragraph 3.5.1.3.

In addition to its space vehicle interface the US must communicate with the MCS via the telecommunications network.

3.5.1.6 Availability Requirements. Referring, in Section 2, to Table 2-3, it is determined that US equipment should be sufficiently reliable to support an MTBF assessment of 100 hrs. And, the equipment maintainability should support an MTTR assessment of 6.95 hours.

3.5.2 Interpretation of Requirements. Because the US also supports the functions of a monitor station, the interpretation of requirements appearing in paragraph 3.3.2 also applies here, with the exception that the demands on BITE would be diminished since the US is manned. However, one must freshly interpret the requirements levied on the uplink, since they are unique to the US.

First, one notes that the EIRP and frequency band requirements serve to establish a range of antenna and transmitter sizes which when paired would provide the required EIRP at S-band -- cost establishes the optimum pair. Next, the pointing accuracy requirements establishes the precision of the initial collimation/calibration of the antenna, the quality of the antenna servo system and the form of the antenna-pointing algorithm used to direct the antenna. Finally,

the requirement for SGLS compatibility, plus the data-rate and mod-index specifications, establishes the design of the baseband and modulation equipment.

Actually, the EIRP, pointing accuracy and mod-index requirements are derived-requirements. The overriding requirement is to deliver a signal to the space vehicle with a C/No sufficient to support a BER of 10^{-5} for a ternary-FSK (SGLS-compatible) signal. By introducing the required C/No plus a 6 dB margin into the uplink power budget one derives the requirements for:

EIRP	+88 dBm, minimum
Pointing Accuracy	within 0.1° Az & El
Mod index	1.0 radian

3.5.3 Upload Station Configuration

A block diagram of the US appears in Figure 3-56. In this figure eight major components are identified, viz:

a. S-band antenna equipment group

b. S-band uplink equipment group

c. L-band antenna equipment

d. L-band downlink equipment

e. US data processing equipment group

f. US computer program resident in data processor

g. Meteorological monitoring equipment

h. Boresight/BITE equipment group

Each of these major components is addressed individually in subparagraphs below. As a guide, the reader is referred to the overall US block diagram in Figure 3-57.

3.5.3.1 S-Band Antenna Equipment Group. The S-band antenna equipment group comprises:

a. 15 foot diameter, parabolic antenna with S-band, transmit-only feed

b. Antenna pedestal and servo system

c. Radome

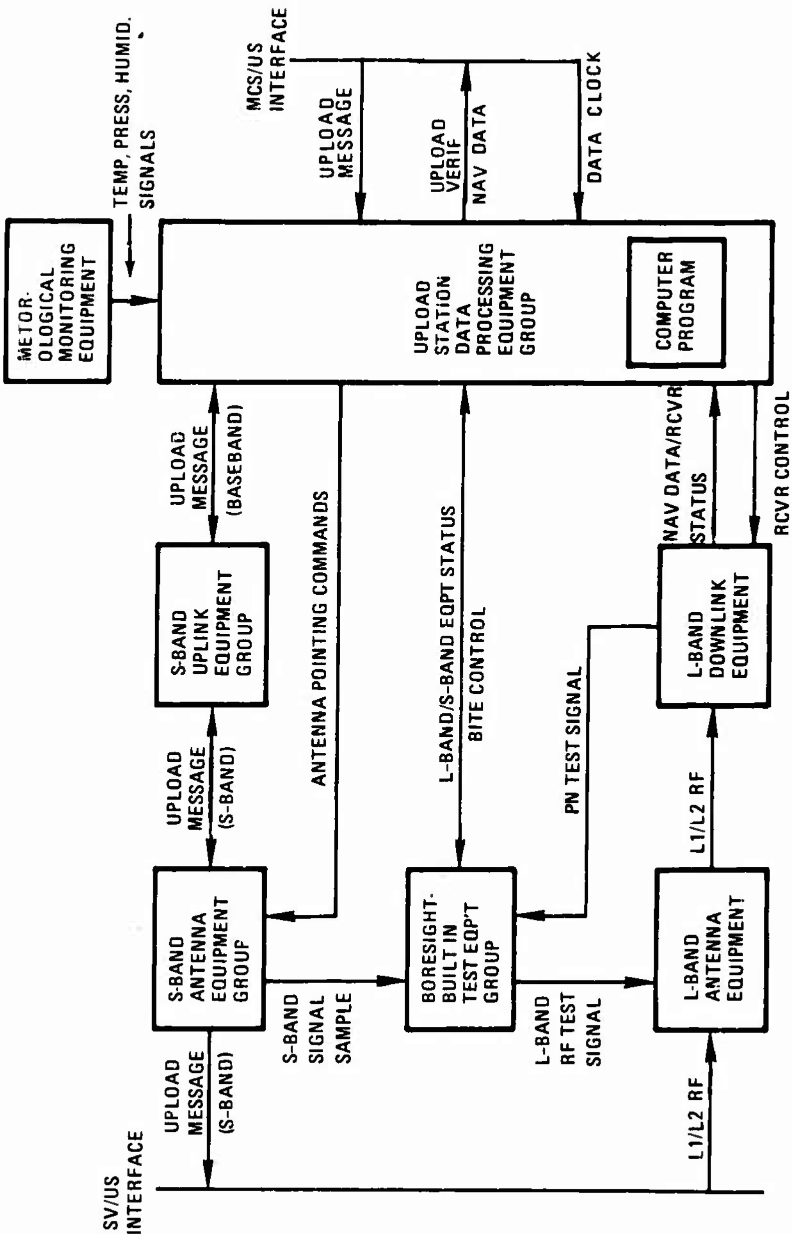


Figure 3-56 Upload Station Block Diagram

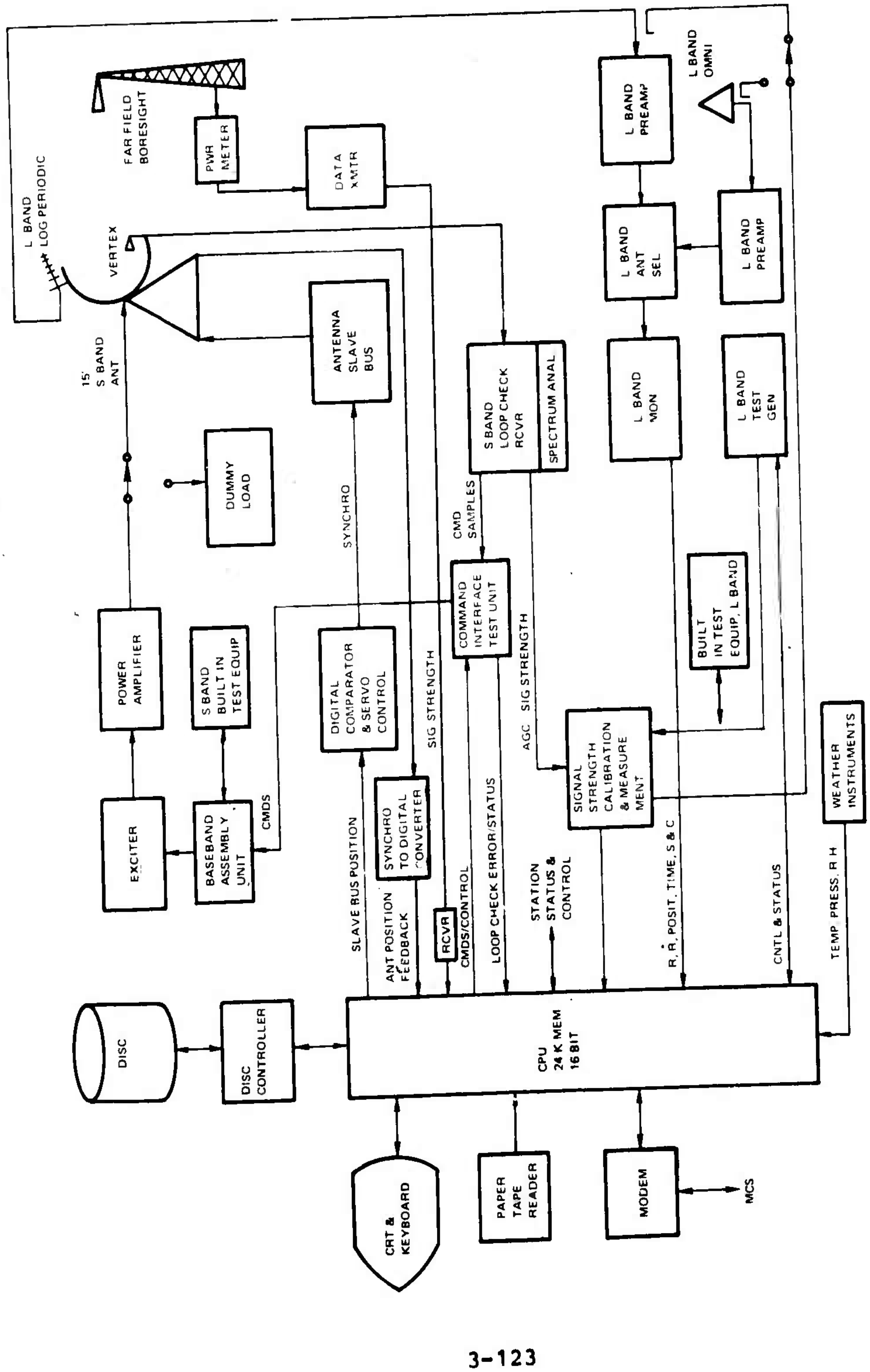


Figure 3-57 Upload Station Detailed Block Diagram

<u>Antenna</u>

Diameter	15'
Frequency band	1.75 to 1.85 GHz
Gain	35.5 dB
Beamwidth, half power	2.5° ±0.5°
Power Capacity	1.25 kW
Losses, transmitter to radiating aperture	Less than 1.0 dB
VSWR	Less than 1.2:1
Polarization	Right hand circular
Feed	Prime focus

<u>Pedestal/Servo</u>

Type	Azimuth/Elevation electric drive	
Acceleration, Az & El	15°/sec²	
Velocity, Az & El	30°/sec	
Angular Travel	±360° Az 0° to 180° Elev	
Stowage	Hand cranks, manual operated brake release and stow pin insertion	
Angular accuracy, static:	Orthogonality	0.02°
	Backlash	0.02°
	Servo, positioning	0.1°

<u>Radome</u>

Size	Diameter	29'
	Base Diameter	16' 4"
	Height	22' 9"
	Weight	2500 lbs
Attenuation	0.7 dB or less at 1.8 GHz	
Boresight Shift	0.03 milliradians	
Solar Radiation	The radome will reflect 95 percent of incident solar radiation	
Environment	The radome will withstand 100 mph winds. It will withstand salt atmosphere of a sea coast location	

3.5.3.2 <u>S-Band Uplink Equipment Group</u>. The S-band uplink equipment group receives FSK and AM modulated data from, the US data processor via a command interface and test unit (CITU). The uplink equipment PSK modulates a S-band carrier with the data and amplifies the resultant signal to 1 kW or 60 dBm. The specific equipment in the group are:

<u>Transmitter Exciter</u>

The transmitter exciter is a crystal controlled FM/PM signal generator operating in the upper L Band region (1700 to 1850 MHz). Its basic specifications are:

a. Level -130 to +10 dBm ±0.5 dB of set level output

b. VSWR 1.3:1

c. Spurious Outputs: 50 dB down

d. PM Deviation: 0 to ±600° continuously adjustable

e. Freq Response: ±1 dB to 3 MHz

f. Harmonic Distortion less than 2 percent

g. Residual PM: Less than 2.5°

n. Modulation Input: ±4 volts into 50 ohm termination

i. Frequency Stability: 5 parts in 10^7 for one hour

Transmitter Driver

The Transmitter Driver is a traveling wave tube amplifier that takes a 4.4 mwatt input and amplifies it to 500 milliwatts suitable for driving a 1 KW transmitter. The characteristic of this unit are:

a. Frequency Range: 1750-1850 MHz

b. Impedance: 50 ohms

c. Maximum power output: 10 watts

d. Nominal Power Output 0.5 watts

e. Noise figure: 40 dB

S-Band Transmitter

The S-band transmitter is a four-cavity klystron, tuneable from 1700 to 2400 MHz with a power output of 1 kW. The klystron transmitter is selected from a widely used transmitter design and has excellent reliability, very low spurious frequencies, built in personnel, and tube safety features, interlock and overload protection. A klystron transmitter is an optimum choice over other types of transmitting tubes providing only one frequency is required. Frequent returning to operate on different channels will wear out a klystron's cavity bellows. GPS needs only a single frequency which is satisfied with a very cost effective klystron transmitter with the following characteristics:

a. Input: 0.5 watts, 50 ohms, Type N Connector

b. Output: 1 kW ±1 dB, 50 ohm coaxial EIA Flange 1 5/8"

c. Spurious emissions: 80 dB below carrier

Command Interface Test Unit

The Command Interface Test Unit receives the upload message from the US computer and converts them into FSK modulation to be transferred to the S-band transmission equipment. A sample of the radiated signal is returned to the command test loop to verify its accuracy. Any bit errors will be reported.

Different delays can be inserted for differences in path lengths when short test loop are selected and tested for bit error checking. A test generator is provided for uplink checkout independent of the computer.

The output of the modulator will either drive the transmitter exciter or, in the short loop test, drive the internal bit detector.

Modulator

The Modulator switches one of three oscillators by means of a FET switch to select the desired output frequency. The FETs are controlled by the three data lines S, 1 and 0, and produce the tone outputs shown below.

	Center Frequency (kHz)
S-tone	65
0-tone	76
1-tone	95
Clock	0.5

The clock is delayed 600 microseconds, divided by 2 and converted into a 500 Hz sawtooth waveform. This sawtooth wave is used to amplitude modulate the selected sinusoidal frequency. This amplitude modulated FSK waveform is amplified and outputted through a line driver. The AM sawtooth modulation is utilized by the SGLS system to regenerate the command clock in the SV and then determine from the FSK whether a 1, 0 or S was transmitted. The output of the modulator drives the transmitter exciter.

S-band Loop Check Receiver

An S-band loop check receiver will demodulate signals received from a horn sampling the transmitted signal. The receiver consists of the following units:

a. 1st and 2nd IF amplifiers

b. Local oscillator

c. PSK demodulator

d. Video amplifier

e. 1800 MHz RF Tuner

f. Spectrum display unit

3.5.3.3 L-Band Antenna Equipment. Same as MS antenna/preamp package -- see paragraph 3.3.3.1.

3.5.3.4 L-Band Downlink Equipment. Same as MS L-band receiver -- see paragraph 3.3.3.2.

3.5.3.4 US Data Processing Equipment Group.

Performance Requirement

The principal function of the upload station processor is to host the US software described in paragraph 3.5.4 and to present compatible input/output parts to other US equipment, such as the meteorological monitoring and built-in test equipment, and to the terminal equipment of the telecommunications network.

Performance Characteristics

To support the US software the US processor will be a general-purpose, digital, scientific mini-computer with the capability of executing the instruction mix presented by the US software at a minimum rate of 60,000 instructions per second. In addition, the MP will have a high-speed random access memory with a capacity of at least 40,000 16-bit words. To satisfy slower-speed (ie, 50 millisecond access time, as opposed to a one microsecond access time, as opposed to a one microsecond access time for the high-speed memory) mass storage requirements the MP will incorporate a 0.84 megaword disc storage unit.

The central processing unit will feature:

a. Hardware index registers, arithmetic registers and general-purpose registers all capable of supporting 16-bit operations.

b. A conventional instruction set including load-and-store, arithmetic, logical, shift, data transfer and test-and-branch instructions.

c. Double-precision hardware that will provide at least 24 bits of precision in floating-point operations.

d. A capability to address all of the random access memory and to direct-address address at least 16,000 words.

A block diagram of the US processor appears as Figure 3-58.

Regarding interfaces, the US processor will provide a high-level analog-to-digital converter and a multiplexer to service the three analog signals from the meteorological monitoring equipment. Eight lines will be reserved for an interface with the CITU. 23 control lines and 60 status/indicator lines will be reserved for boresight BITE input/output. And a half-duplex synchronous, RS232C-compatible 2000 bps modem interface incorporated to service the telecommunications equipment.

A man/machine interface will be provided via a CRT/keyboard terminal duplicating the three MCS terminals (see para. 3.4.4.3).

In addition the US processor will provide an interface to the antenna and will deliver to the antenna equipment two digital position commands. One command will represent an antenna azimuth of 000.00 deg to 359.99 degrees, and the other, an antenna elevation of -180.00 deg to +179.99 deg. The processing equipment will also deliver two digital rate/slew commands representing 0.1 percent to 100.0 percent of the antenna-drive rate-capability in azimuth and elevation, respectively, plus a "clockwise-counterclockwise" command. The application of the position and rate commands are to be mutually exclusive. The command update rate shall be the minimum required to support an antenna pointing accuracy of 0.1 degree, azimuth and elevation, but should not exceed 10 per second. This interface shall be transistor-transistor-logic (TTL) compatible.

Provisions for power loss (or out-of-tolerance conditions) will also be incorporated in the US processor. That is, sensing of an imminent power loss will initiate the storage of key registers and the random access and disc memories will be protected from alteration. When power is restored they will be capable, using a bootstrap program stored in a non-volatile (read-only) memory, to automatically restart.

3.5.3.6 Upload Station Boresight and BITE. The boresight facility for collimating the uplink transmitting antenna consists of a boresight tower supporting a directional antenna which is pointed at the US transmitting antenna, an r-f cable from the antenna to the base of the tower and the control cabinet. The control cabinet is a weatherproof enclosure with an access door on the front. Within the box are a power panel for the equipment and aircraft obstruction lights, an r-f power meter, a data send and receive unit and a telephone.

The antenna is a right-hand cicularly polarized, 20-dB, ±1dB, gain standard horn having less than 1 dB ellipticity. The exact value of gain is not critical, but the gain at the working frequency is to be calibrated to within ±0.25dB. The coaxial cable leading down to the

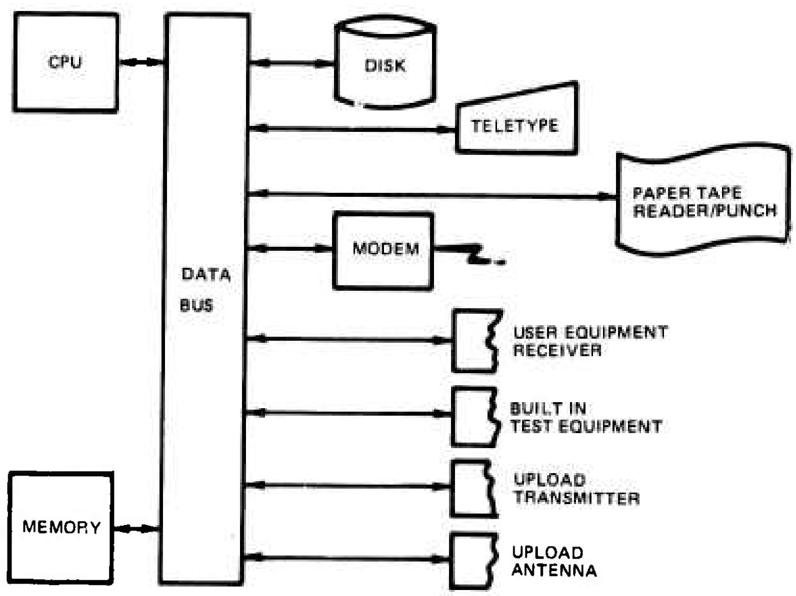


Figure 3-58 Upload Station Data Processor Configuration

instrumentation enclosure is RG-214 A/U, with approximately 15 dB loss per 100 feet run.

Power received by the antenna is measured by a power meter having autoranging, dBm readout, and BCD data outputs. This instrument measures power levels between +10 dBm and -50 dBm.

The data provided by the power meter is transmitted by an asynchronous parallel-to-serial converter and line driver, via a telephone pair to the US processor. A data receiver provides full duplex communication and control. The instrument power on/off, obstruction light control, and main power on/off can be controlled from the US.

The power received at the boresight tower antenna is computed for a distance of half a mile, 1000 feet, with a 15 foot transmitting antenna, a 1-kW transmitter, and a 20-dB BST antenna.

Transmitter Power	60 dBm	
Waveguide 50' WR-430	-0.28 dB	
Rotary Joints @ 0.1 dB ea.	-0.20 dB	
Feed Loss	-0.40 dB	
Antenna Gain	35.50 dB	
EIRP		92.90 dB
Space Loss		-87.20 dB
Receive Antenna Gain	20.00 dB	
BST Cable	-12.00 dB	
Net Gain		8.00 dB

Received power at boresight instrumentation 13.70 dB

This value of BST received power is near the upper limit of the instrumentation range, and thus affords a 40-dB useful range of power for antenna pattern measurement.

At the US, the antenna shaft angles are input to the processor along with the BST power levels corresponding to them. When data collection is complete, the angles and pwoier are printed out on the TTY.

The BITE in the US is charged with monitoring the performance of the transmitter, its exciter-modulator and the air check monitor. The US incorporates the equivalent of a monitor station, and utilizes the MS-type BITE's DVM and counter to monitor US performance. The input switches for the DVM and counter in the MS will hand control over the US input switches. The US voltage functions to be monitored are:

Aircheck receiver input voltage*

Aircheck receiver output video voltage

Exciter power*

Exciter modulator input

Baseband assembly input logic levels

Baseband assembly output video level

Uplink detector cutput logic levels

Uplink detector AM percentage

Modem inputs

*Measure DC analog output of crystal detector.

The US frequencies to be measured are:

Upink carrier frequency

FSK baseband frequencies

3.5.4 Upload Station Software

The Upload Station is the final link in the primary control segment support function. The software which supports this function at the US has been designed around a slave and forward approach.

In a nominal upload sequence, the US is designed to receive upload data from the Master Control Station, store the data and, when the schedule dictates, forward the data to the Space Vehicle. During normal operations, these activities have been designed to progress without need for operator intervention. The design is also based on co-existence in the upload station computer with the software functions performed at a typical monitor station. Both sets of software operate concurrently, sharing common communications impact on each other. The following sections describe those upload functions allocated to the US software in terms of the actual implementing computer programs. Figure 3-59 shows the interrelationship of the programs in the upload software.

3.5.4.1 Navigation Upload Control. Control of the upload process at the US involves two distinct forms of controls: control by the scftware or the message reception and storage, process initialization, and reporting to the MCS; and support of backup control of the real time process by a local operator. Figure 3-59 shows the programs involved in this process. Four types of data come from the MCS to initialize and control the upload station:

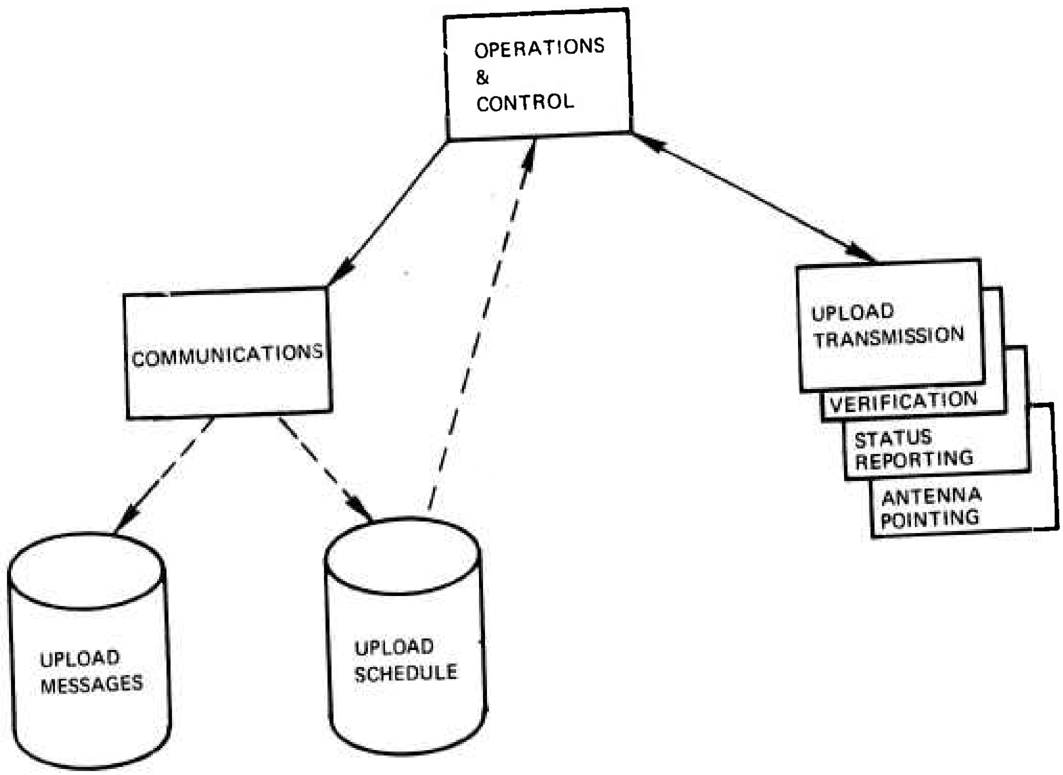


Figure 3-59 Upload Control

a. Station Schedule

b. Upload Messages

c. Initialization parameters which define the upload mode, ie, reject level, message to be transmitted, vehicle to be loaded, etc.

d. Real time controls which start and stop transmission, bypass verification, bypass echo check, etc.

The first three are received from the MCS prior to the upload process and stored on the upload station disc as follows: 1) the station schedule on a weekly basis, 2) the upload messages just prior to upload, 3) the initialization data as required. All the data has been formatted at the MCS so that a minimum of additional processing is required at the MCS, thereby minimizing the possibility of errors being injected into a message at the upload station. Upload messages are tagged such that they can be retrieved by number for a given pass, thereby allowing backup and recovery message storage at the US for use as necessary.

The US Operations and Control Function and the Communications Function are the same programs used in the monitor station CPCI, being designed to handle the requirements of both stations. As previously identified, US operation has been designed to progress without operator intervention under normal operations, although intervention and complete take-over can occur at any time. The Operations and Control Function will interpret the local schedule and bring the Upload Transmission, Verification and Status Reporting Functions into execution at the appropriate times with control parameters necessary to complete an entire upload operation (ie, load all vehicles requiring service during the pass). The schedule will include acquisition and fade times, load start times, vehicle IDs, message IDs, etc.. During the upload process operator intervention/control is supplied to these three real time functions directly, if local (back-up) control is used, or via the Communications Function if MCS control is being exercised. The following specific control inputs may be used at appropriate points in the real time process:

a. Transmit/Stop

b. Frame number

c. Verification bypass

d. Increment secure keyword

e. Loop test/radiate

f. Set reject level

The effects of these commands are discussed in the following discussion of the Upload Transmission and Verification Processes.

3.5.4.2 Upload Transmission and Verification. Figure 3-60 shows how the four real time programs involved in the upload process interface. When the Transmit input is given, either from the schedule or from operator input, the Transmit Program retrieves a frame of message data, adds preamble and postamble sequences and the appropriate key, validates the frame error detection bits, and converts the binary coded data to the SGLS ternary code. This frame is output to the transmitter interface and another frame of data is retrieved from mass storage and prepared for transmission. At the completion of transmission of an individual frame, the Upload Verification program is initiated to extract the command verification telemetry word from the L-Band downlink frame. If an accept is detected, transmission of the next frame is enabled. If a reject is detected, the previously transmitted frame is transmitted if the reject level has not been exceeded. If the reject level is exceeded, an alarm is sent to the operator in charge. He may choose to bypass the verification process in an attempt to bypass a failure in the downlink receiving equipment.

In support of this real time transmit/verify process, the Upload Status reporting program provides real time status feedback to the operator giving acquisition times, times of transmission frame numbers, reject level, reject alarm, and other pertinent status data. At the completion of a load pass it summarizes pertinent upload process data, including:

a. Load time of each frame

b. Frame numbers loaded

c. Number of retrys

d. Frame numbers rejected

e. Frames transmitted under bypass mode

Also operating concurrently with the above programs is the antenna pointing function. Antenna pointing angles are obtained locally via calls to the monitor related function which computes satellite position from the acquisition almanac. Interpolation is provided as necessary to assure that the antenna does not exceed the maximum slew rate and provides the required signal strength. Capability is provided to allow the operator to specify a desired antenna position for special tests.

Uplink readiness testing is achieved by operator selection of the loop test mode, specification of a "safe" antenna position, and selection of a test or operational message for transmission. Echo data will be captured and compared with the transmitted data on a bit-for-bit basis. Appropriate status data will be generated.

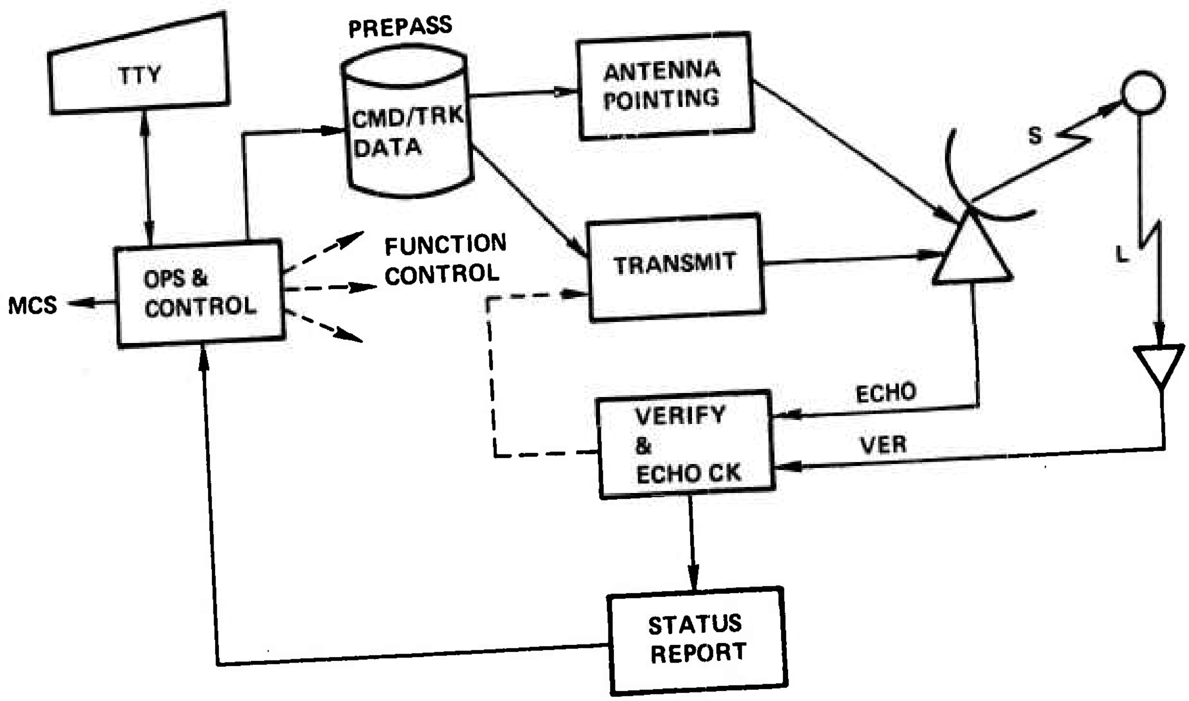


Figure 3-60 Upload Realtime Processes

3.5.5 Configuration/Installation Design of the Upload Station

This paragraph includes those requirements and standards for the installation of the GPS Upload Station (US) to achieve an integrated site installation of all technical equipment in building 22104 of Vandenberg Air Force Base, California. The US equipment will be installed within the same area as described in paragraph 3.4.5 for the Master Control Station. In addition to the equipment racks and cabinets to be installed within building 22104, an S-Band antenna with radome will be installed on the roof of the building, farfield boresight facility will be located on a new tower north of the building, and a monitor station L-Band conical antenna will be mounted approximately 60 feet high at a distance of about 50 feet northwest of the building. The location of the S-Band antenna on the roof of the building will allow transmission of signals to GPS space vehicles at any azimuth elevation above 5 degrees. Space will be provided for maintenance work, storage of test equipments and spare parts.

3.5.5.1 Site Configuration. All the equipment of the US will be installed in the vicinity of building No. 22104. The location of the building, power substation, boresight tower, transmitting antenna radome, L-Band receiving antenna, and weather measuring equipment is shown in Figure 3-61.

Room Arrangement

The racks for US equipment will be located in room 102 of building 22104. This equipment room also houses the MCS racks as described in paragraph 3.4.5.2. Five racks of US equipment will be located in this room as shown in Figure 3-62 and 3-63. This arrangement will provide minimum signal transmission line losses occuring between the transmitter and the antenna. A desk mounted display terminal with an alphanumeric keyboard will be installed in room 103 as shown in Figure 3-62. Total floor area required for the US will be less than 200 square feet. Double doors, giving an entrance 6 feet wide are available to facilitate installation or removal of the US equipment into or out of the building. Rack positions will be adjusted as necessary to avoid cutting of structural members. Racks and cabinets will be mounted in a manner that will ensure mechanical stability under worst case conditions of equipment chassis slide positioning or anticipated possible seismic loading. Adjacent racks will be fastened together at top and bottom with fronts aligned to within 1/16 inch.

Rack Arrangement

The US equipment will be arranged in the following listed racks as shown in Figure 3-64:

a. One US Processor rack

b. One Test/Loop Check rack

c. One Exciter/Servo rack

d. One L-Band Equipment rack

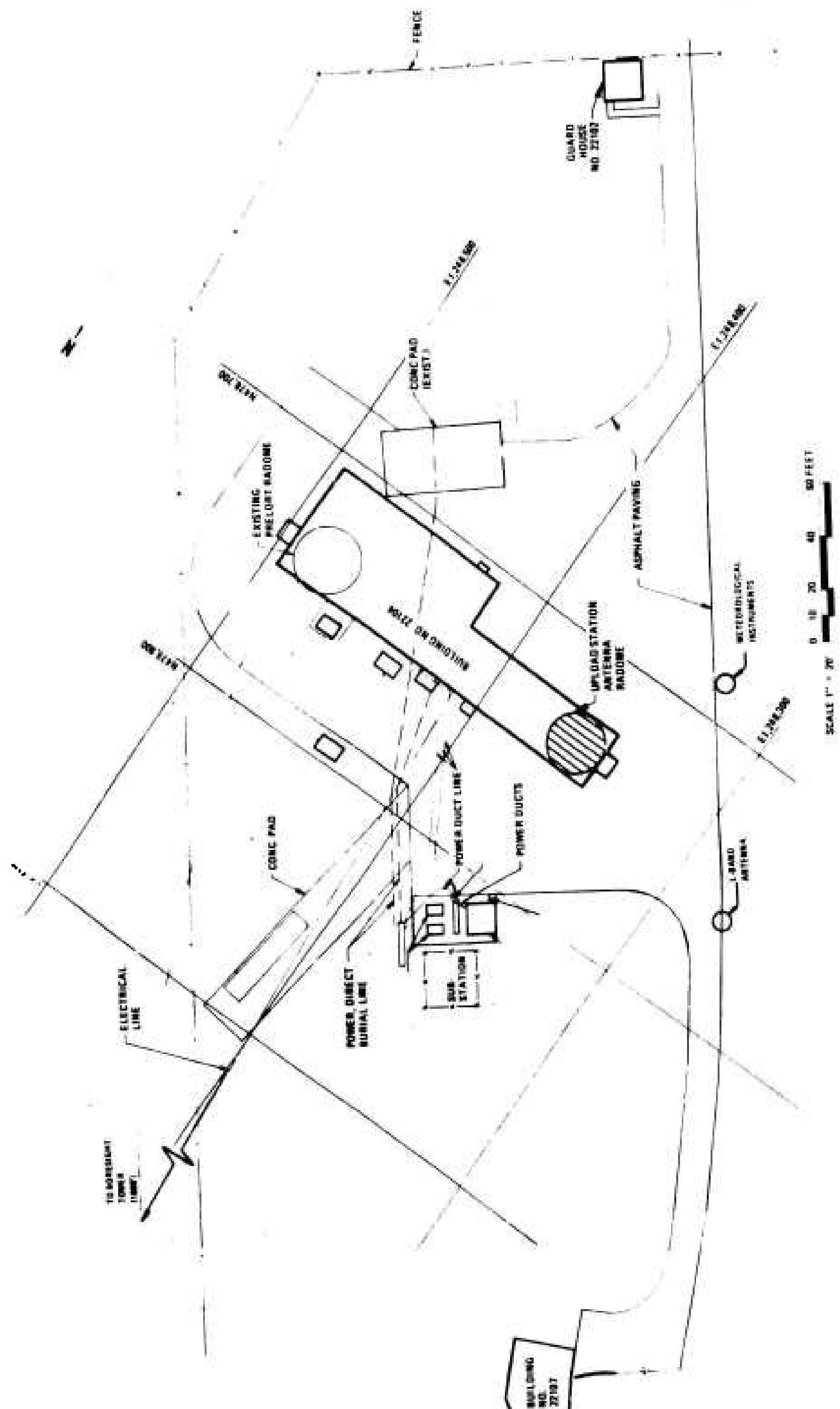


Figure 3-61 Upload Station External Equipment

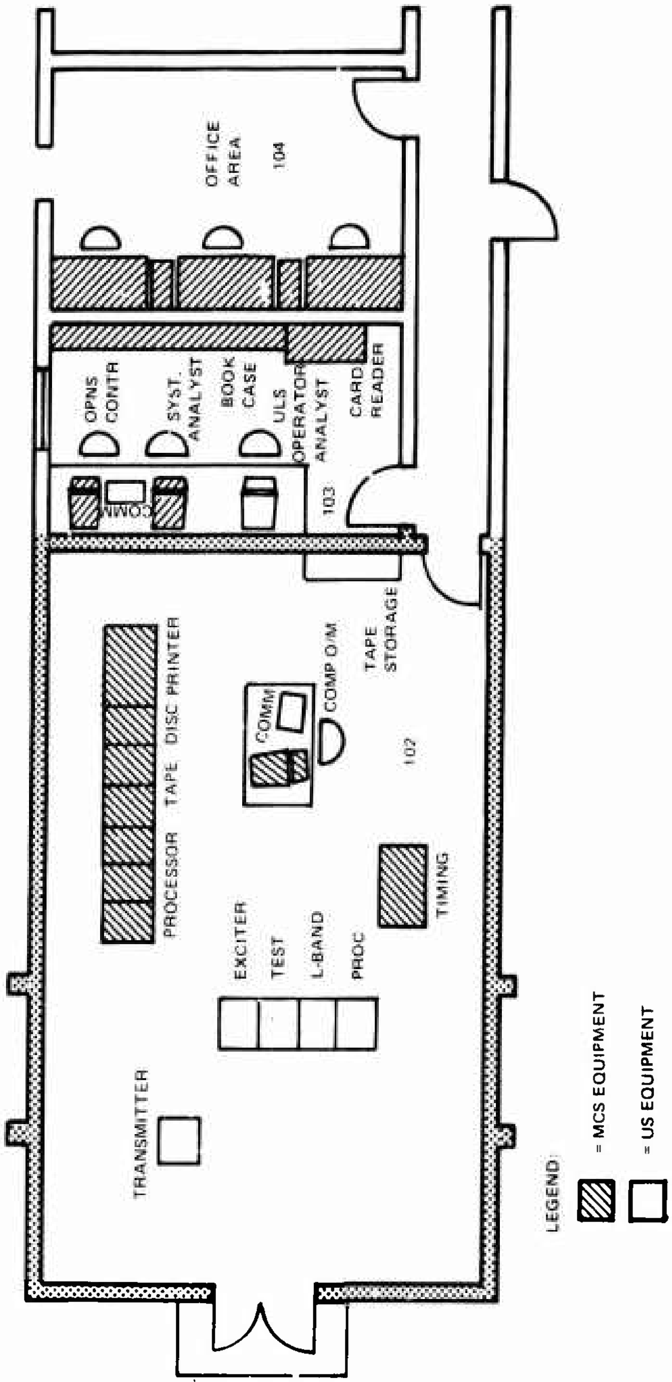


Figure 3-62 Upload Station Equipment Layout
Vandenberg AF Base - Building 22104

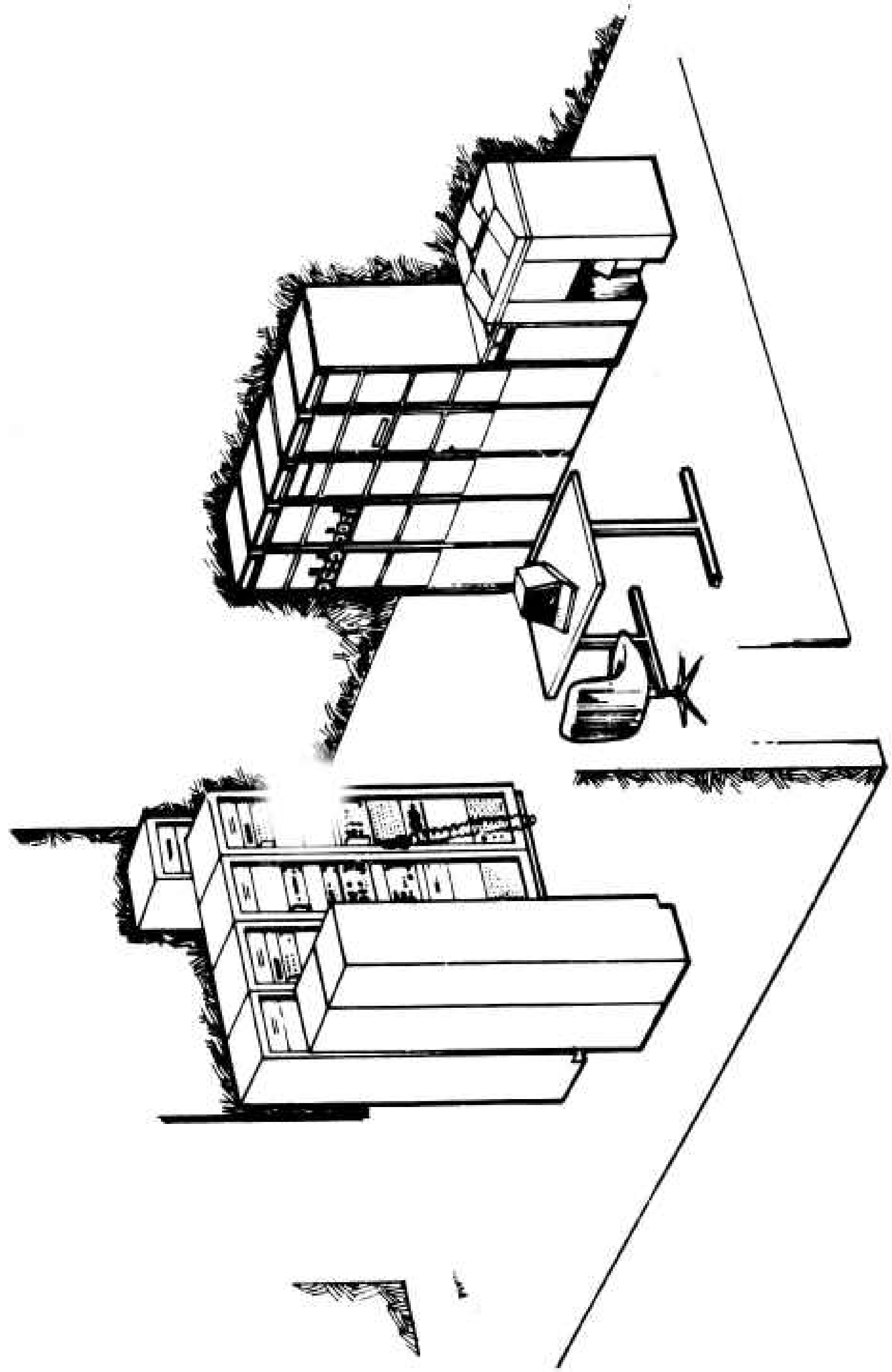


Figure 3-63 Artist's Conception of the MCS/US Equipment Area

PHILCO
Philco-Ford Corporation
Western Development Laboratories Division

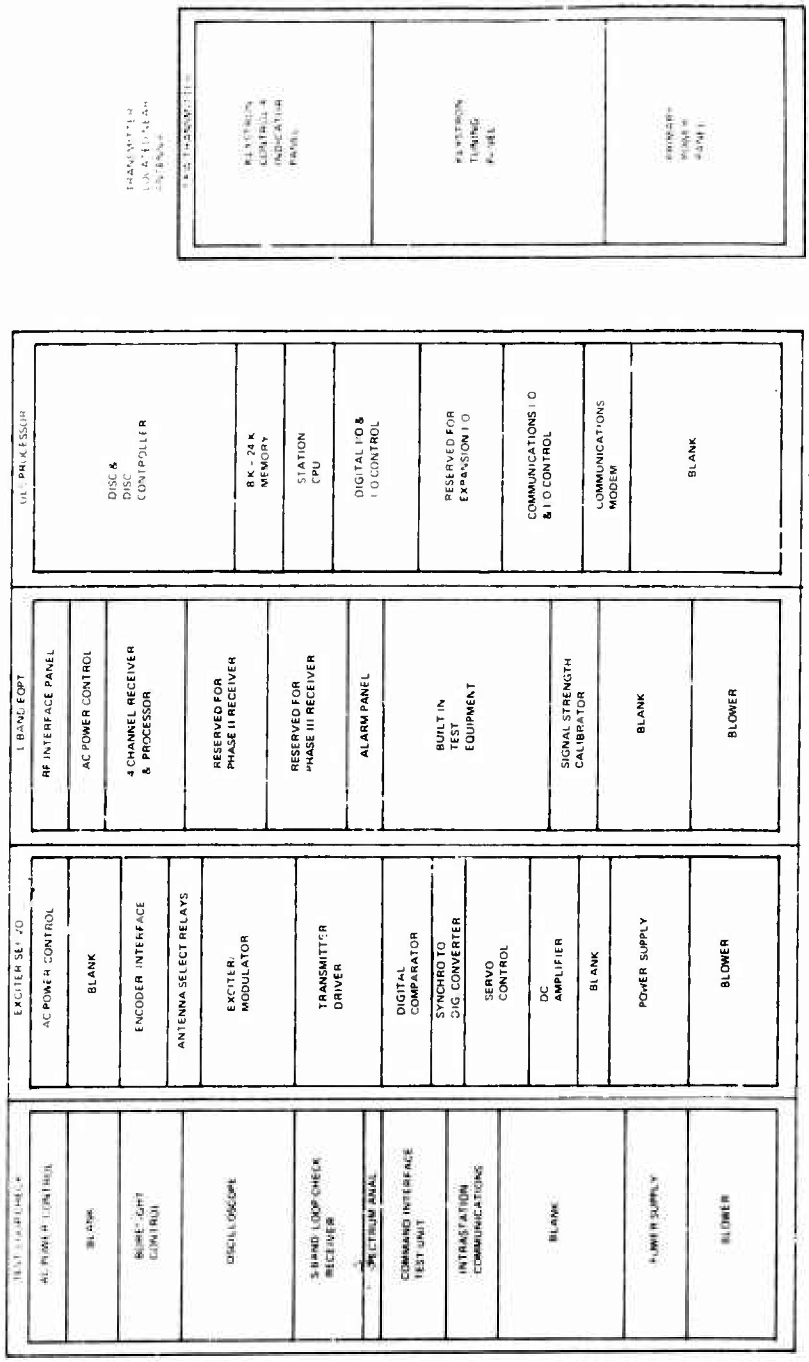


Figure 3-64 Upload Station Rack Elevations

e. One Transmitter rack

All the racks, except the transmitter rack, will be standard 19-inch panel width, with overall dimension of 24 inches wide, 30 inches deep, and 82 inches high. The dimension of the Transmitter rack will be 24 inches wide, 30 inches deep, and 72 inches high. All cabling access to these racks will be through the bottom of the racks. The waveguide between the antenna and the transmitter will be through the top of the rack.

Building Support Services

a. Lighting. The US equipment area will be augmented with lighted fixtures to provide an approximate uniform lighting intensity of 100 foot-candles measured 30 inches above the floor. Fixtures will be provided with necessary louvers to prevent undesirable shadows or reflections on the front of technical display units. Lighting fixture types will be similar to that already in use within building 22104.

b. Convenience Outlets. Duplex Convenience Outlets of the self grounding type will be installed near the US equipment to augment present outlets in order to provide the outlets at a minimum of 12 feet centers.

c. Cooling Requirements. The US equipment will dissipate approximately 75,000 Btu/hour and the primary method of cooling will be circulation of conditioned air through the equipment racks. The air is supplied to the room and will be supplied to each rack by a blower located in the rack. The warm rack air will be exhausted into the room from the top of the racks.

3.5.5.2 Antenna Installation. The US S-Band 15-foot diameter transmitting antenna and 29 foot diameter fiberglass radome will be installed on the concrete roof of building 22104 as shown in Figure 3-65. The antenna pedestal will be located directly above the transmitter rack in room 102 below. The horizontal center line of the antenna will be installed so that it is 10 feet (maximum) below the top of the SGLS radome on the other end of building 22104. The building is designed to resist 120 knot winds and a non-simultaneous zone 3 magnitude seismic load, as defined by the National Uniform Building Code. The building roof is presently reinforced to carry the antenna, pedestal and radome loading of approximately 4 tons.

The radome will provide a 95% rejection of solar radiation and protect the sheltered equipment from exposure to sand, dust, precipitation and fog. The interior temperature range will vary between approximately 40°F and 110°F. A ventilation system circulates temperature controlled air within the radome in order to limit vertical stratification to 10°F, and to minimize effects of condensation.

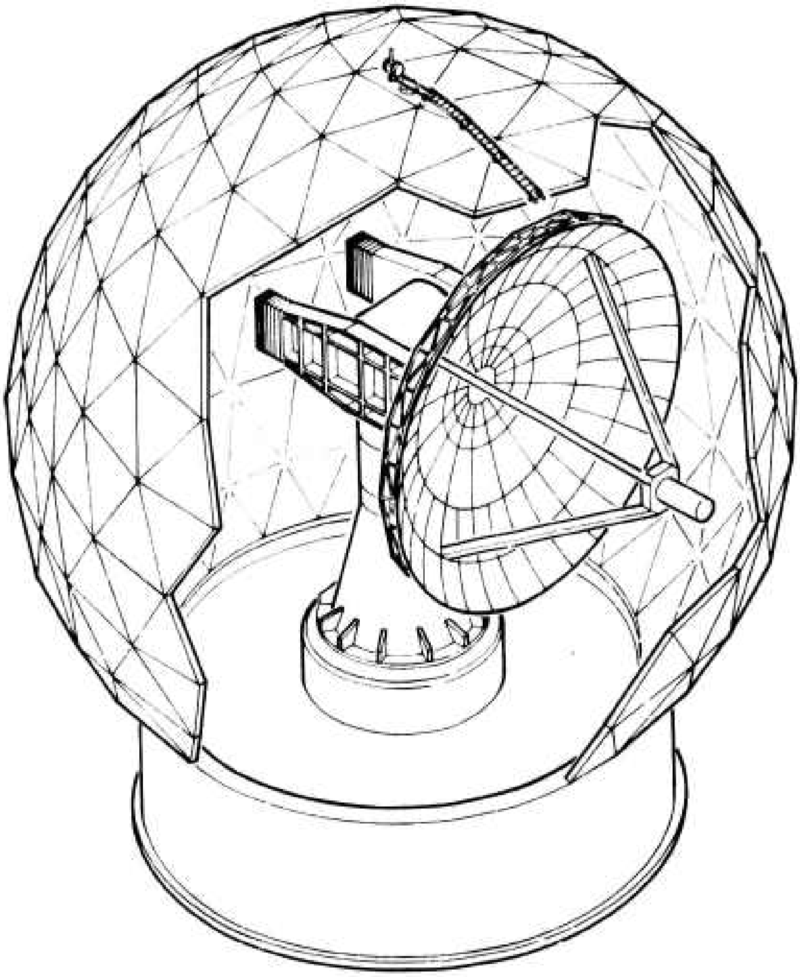


Figure 3-65 S-Band Antenna and Radome Installation

3.5.5.3 Boresight Installation. A boresight tower will be located approximately 1000 feet north of building 22104. The boresight tower will be 100 feet high and teh US boresight antenna will be mounted 88 feet above the ground. No optical target shall be provided. The tower will be guyed to limit swaying at the top to less than ±12 inches maximum in 120 knot winds. The antenna will be connected to a weatherproof instrumentation enclosure not smaller than 3'x3'x1', which may be mounted on the tower or standing nearby. Power for obstruction lights and for the instrumentation will be installed at the base of the boresight tower via buried cable and terminated at a breaker in the instrumentation enclosure. Communications calbe, will be installed as described in paragraph 3.5.3.6. The communication cable will terminate at a lightining arrestor at each end.

3.5.5.4 L-Band Antenna Structure. The L-Band antenna will be mounted on a 60 feet high tower at a distance of 100 feet on a westerly bearing from the NW corner of building 22104. See Figure 3-61. The structure will be guyed to limit swaying at the top to less than ±12 inches maximum in 120 knot winds. Cabling for obstruction lignting power will be buried underground and terminated at both ends in a circuit breaker panel.

3.5.5.5 Electric Installation Standards. The US equipment will require approximately 20 kW of electric power to be provided. All new i stallation of electric service system will be in accordance with the standards described in paragraph 3.4.5.6 of this report.

3.5.5.6 Ground System. The present station ground systems are described in paragraph 3.4.5.7 and US equipment will be grounded in accordance with the requirements stated in paragraph 3.4.5.7.

3.5.5.7 Instrumentation Cabling. Inter-rack cable assemblies will be installed in accordance with the standards set forth in paragraph 3.4.5.8 of this report.

3.5.5.8 Radiation Hazards. Tests will be conducted to ascertain the radiation field and density levels in accordance with the GPS electromagnetic compatibility (EMC) plan. When tests or analysis indicate a potential hazard as defined in AFM161-7, Control of Hazards to Health from microwave radiation, and AFM 127-100, Explosive Safety Manual, the areas will be suitable posted with warning signs.

3.5.5.9 Lightning Protection. Lightning protection meeting the requirements of the Lightning Protection Code NFPA No. 78 will be provided for the S-Band antenna radome, L-Band antenna support, and the weather instrumentation tower, and the boresight tower.

3.5.5.10 Obstructions to Air Navigation. The S-Band antenna radome, L-Band receiving antenna support, the boresight tower, and the weather

instrumentation tower will be lighted and/or painted as determined by Federal Aviation Regulations, Part 77, and in accordance with the Federal Aviation Agency (FAA) publication entitled, Obstruction Marking and Lighting.

3.6 TELECOMMUNICATIONS NETWORK DESCRIPTION

This final subsection of Section 3 addresses the hardware required to implement the GPS Telecommunications Network (GPSTN). The network configuration documented in this SAR represents the least expensive approach to providing the GPS/CS with an independent (ie, not shared) telecommunication service that meets the CS functional requirements allocated to it.

3.6.1 GPSTN Requirements

In the system specification for the CS a single function -- communications -- is allocated to the GPSTN. Quoting the specification:

> "...The telecommunications network is allocated the CS function of implementing the ground-based, extra- and intra-segment interfaces. Specifically, the network shall provide land-line communications to/from the MCS and the US, MS, AFSCF and RCF. The network shall utilize voice-grade lines requireing no special conditioning and shall employ dial-up or dedicated service as dictated by mission time-lines/support requirements. All communication interfaces shall provide for data exchange as well as for a voice (or TTY) order wire on a mutually exclusive basis..."

Regarding mission time-lines/support requirements, one notes, for example, in Figure 3-19 that the usage of the MCS/MS communication lines would barely exceed 1.25 minutes per hour during Phase I. Further, communication with the RCF will occur only on a weekly basis while communication with the SCF will possibly take place on a daily basis. In any event there appears to be no requirements for dedicated lines from the MCS to any location except the US. This is because of the time-critical nature of the upload sequence. Until the US moves away from the MCS no control segment communication circuits will require service exceeding that available on dial-up lines.

3.6.2 GPSTN Configuration.

Figure 3-66 establishes the relationship of the GPSTN to the other elements of the CS, showing the ground communication interfaces implemented by it. Each of these interfaces is described below.

3.6.2.1 MS/MCS Interface. The Hawaii and Alaska links from VTS will be satisfied by standard voice grade telephone dial-up circuits. These links are 2-wire circuits which may consist of satellite, submarine cable, or microwave segments. Because of the path variation

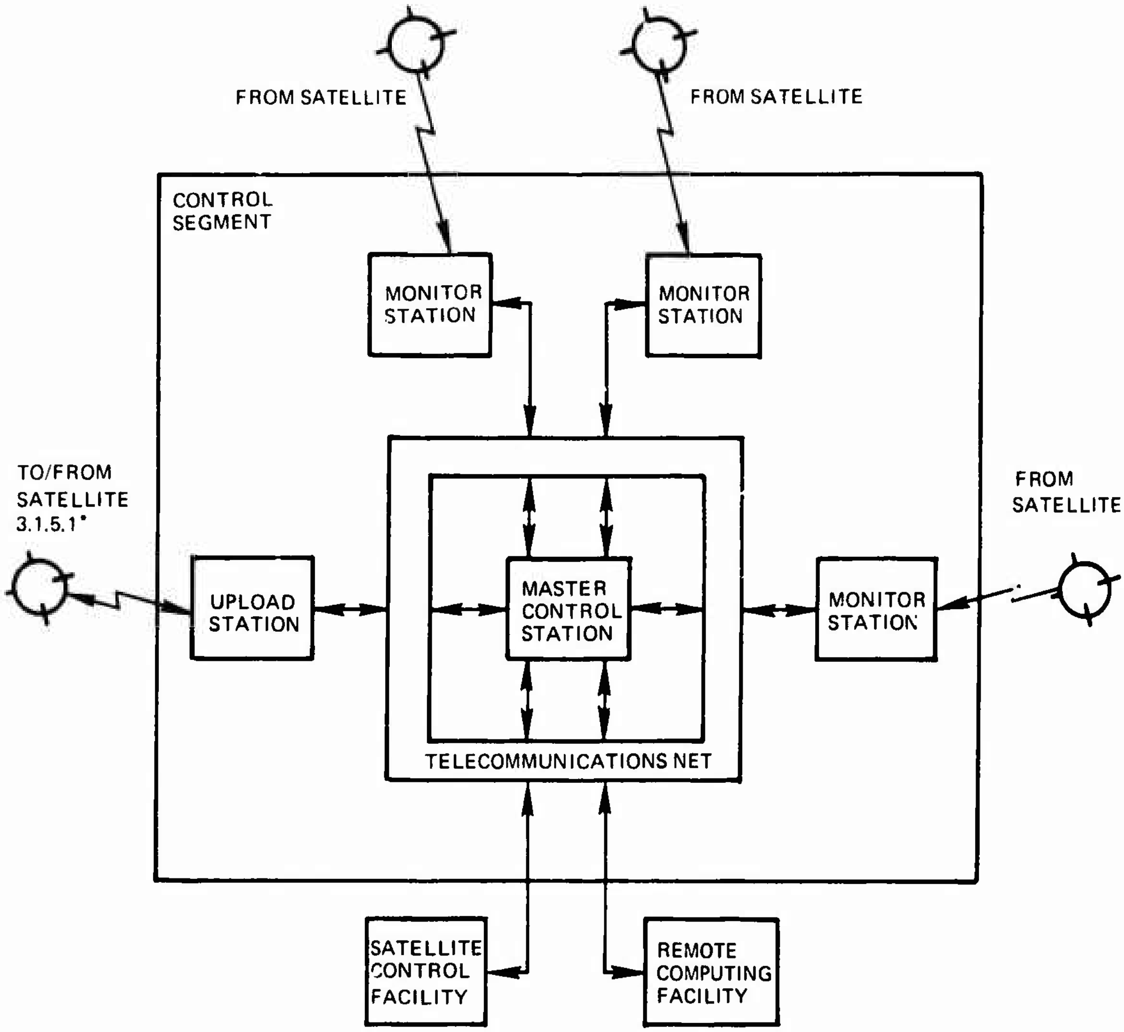


Figure 3-66 Control Segment Interface Block Diagram

for each call, the transmission response times may vary greatly between calls. Direct Distance Dialing is possible with AT&T 801 A/C Automatic Calling Units; however, the system must be designed to withstand response variations which may occur. Transmission will be half duplex 2000 b/s, and the call frequency will be once per hour, automatically controlled. Voice (order wire) communication is possible on the lines between data transmissions. Figure 3-67 provides the details of the MCS/MS interface.

3.6.2.3 US/MCS Interface. The MCS link to the US should be a dedicated 4-wire unconditioned line. Transmission on this line will be half duplex to conform with the dial-up lines in the system. Because the circuit is 4-wire, the half duplex operation will be improved by eliminating line turnaround times. Transmission rates of 2400 or 4800 b/s can be used on the dedicated line. This interface is shown in Figure 3-68.

3.6.2.3 RCF/MCS Interface. The link from VTS to the RCF in Virginia will be satisfied by a standard voice grade telephone dial-up circuit. This link will experience some variations in response time, but it will be less than that for the Hawaii and Alaska link. Connection to the RCF will be made manually by an operator, for convenience and to enhance communication with the RCF. Communication is expected to be limited to one or two calls per week. Transmission will be 2000 b/s, half duplex. Figure 3-69 depicts this interface.

3.6.2.4 SCF/MCS Interface. A manual dial-up link will be used to interconnect the MCS and the GPS Tape Receiver System in the SCF. Figure 3-70 shows the MCS/SCF link.

3.6.2.5 Link to the "Roving" MS. The link to the third monitor station will be established by a standard voice grade telephone dial-up circuit if the station is located in CONUS. In this case, the communication will be at 2000 b/s, half duplex. The call frequency will be once per hour, automatically controlled. If the third statin is located outside CONUS, AT&T will not suppport data communications over dial-up circuits. Transmission over dial-up circuits may still be possible by using equipment supplied by vendors other than AT&T.

3.6.2.6 Data Processor/Modem Interface. The processor/modem interfaces at the MCS, US and MS should comform with EIR Recommended Standard 232C.

Automatic calling units (ACU) will all be located at the MCS and interface the MCS processor through calling unit adapters.

3.6.2.7 Modem Characteristics. The following list of modem characteristics presents typical specifications for modems suitable to the GPSTN applications.

Line Requirements	Operates half duplex over 2-wire DDD or unconditioned leased lines. Operates

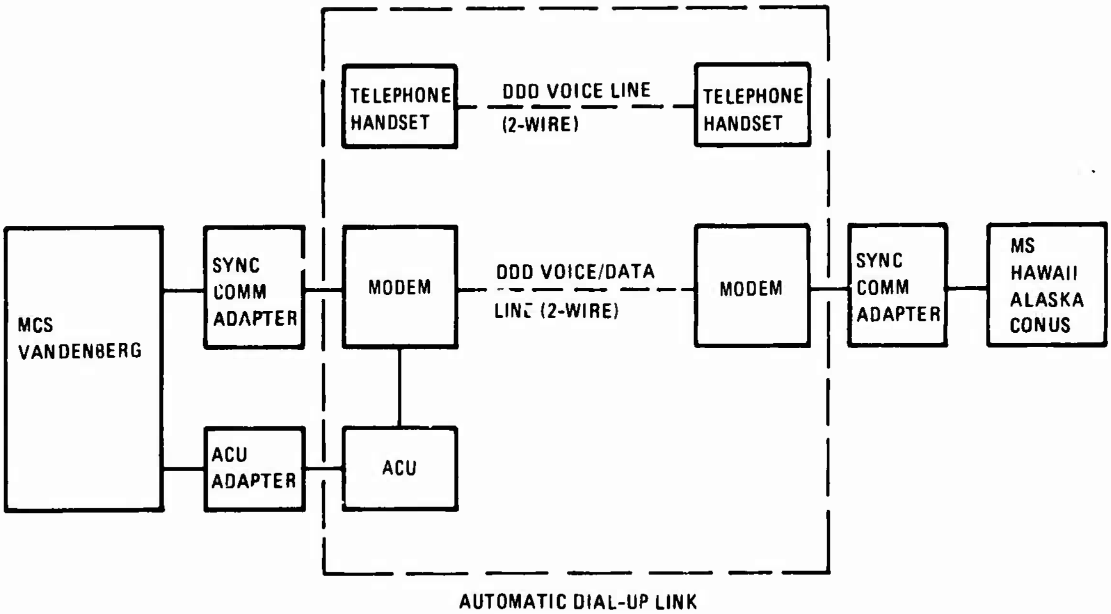


Figure 3-67 MCS/MS Communication Link

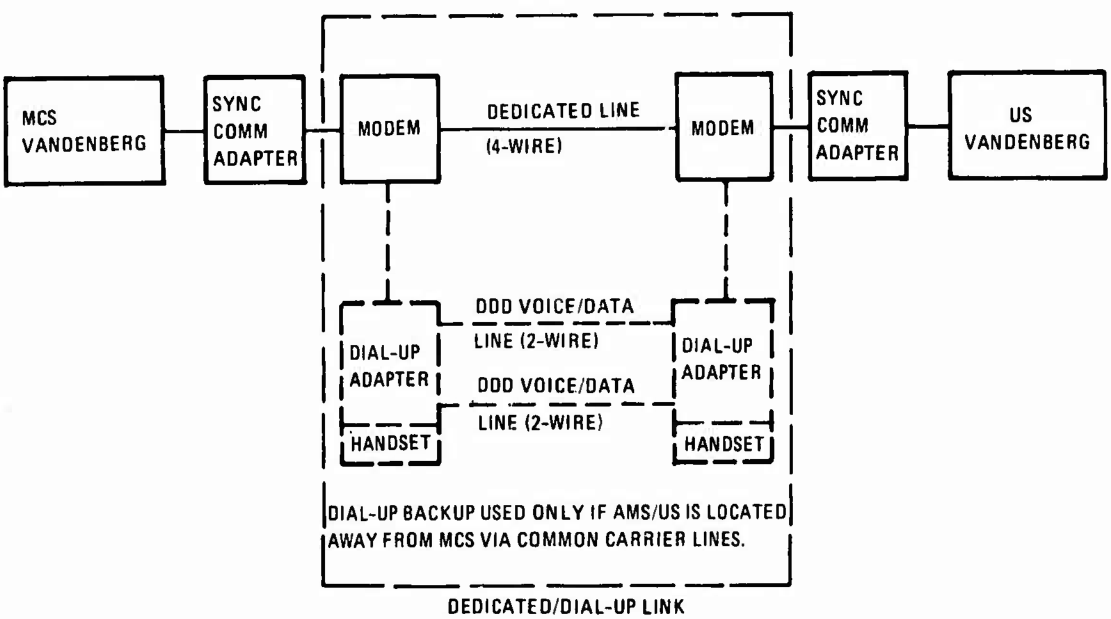


Figure 3-68 MCS/US Communication Link

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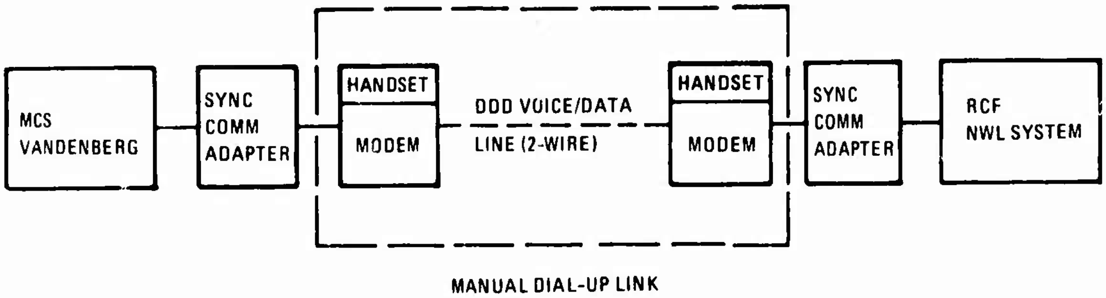

Figure 3-69 MCS/RCF Communication Link

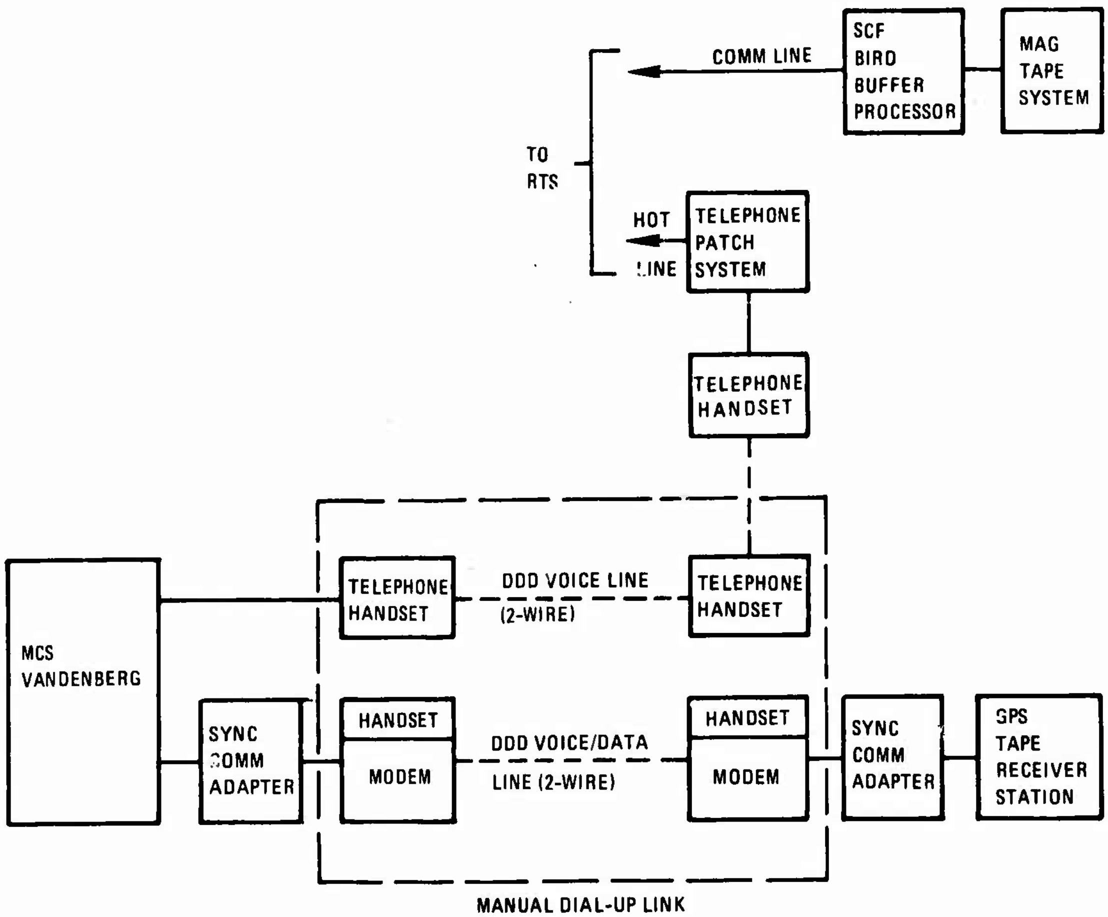

Figure 3-70 MCS/STC Communication Link

	full duplex over 4-wire unconditioned leased or two dial-up lines.
Transfer Rate	2000 b/s minimum
Transmitter:	
Input Data	Serial binary, RS-232C, single wire with ground return, input load between 3000 and 7000 ohms.
Input Clock	Squarewave with negative-going edges coinciding with center of data bits, positive edges coinciding with change of input data. Accurate to ±.01 of transfer rate with 50 ±2 percent duty cycle.
Output to Line	Output impedance of 600 ohms resistive, balanced. Output level of 0 to -14 dBm adjustable in 2 dB increments.
Receiver:	
Output Data	Serial binary, RS-232C, single wire with ground return. Output impedance 300 ohms, nominal.
Output Clock	Squarewave with negative-going edges coinciding with center of data bits, positive-going edges coinciding with change of output data. Clock derived from the received line signal. Frequency equal to the data bit rate and synchronized with the transmitter clock.
Input from Line	Input impedance 600 ohms resistive, balanced. Selectable nominal input level between -10 and -40 dBm in at least 4 steps. 25 dB dynamic range about selected nominal input level. Normal operation of Received Line Signal Detector at 12 dB below selected nominal input level.
Test Features	Digital interface and line interface test loops which can be manually controlled or automatically controlled from remote modem.
Operational	Two-wire DDD and 801 ACU (with CBS if non

Configurations	Bell) Two-wire DDD (with CBT if non-Bell) Four-wire private line (no DAA) Two-wire private line (no DAA)
Operating Environment	Ambient temperature range of 0 to ±50 deg C Relative humidity (maximum) 95 percent Altitude up to 10,000 feet
Indicators	Received line signal detector light indicating the ON condition of this signal. Test mode light indicating that the modem is in one of the test loop configurations.
Primary Power	or input at either 105-125 or 210-250 VAC, 50/60 Hz single phase, power cable supplied

3.6.2.8 Overall GPSTN Performance/Design Characteristics

Transmission rate of information bits

All of the links in the GPSTN will be designed and configured to provide a transmission rate of information bits (TRIB) of 1500 b/s or greater. The TRIB is defined as the ratio of the number of information bits accepted by the receiving data terminal equipment during a single Information Transfer Phase to the duration of that Information Transfer Phase. The TRIB of 1500 b/s is based upon transferring 10,000 bit data blocks under ANSI X3.28 control procedures described in the U.S. Department of Commerce, National Bureau of Standards Technical Note 779.

Error performance

In order to meet the TRIB of 1500 bps it is anticipated that the GPSTN should have a burst error rate better than 1.0×10^{-5} as described in NBS Technical Note 779 section 7 for a modem rate of 2000 b/s.

Transmission rate.

Each link of the GPSTN will transmit data at 2000 b/s minimum under control of timing supplied by the synchronous modems.

Line equalization

The modems which are configured into any of the GPSTN links will contain either compromise or automatic adaptive equalizers to aid in attaining the TRIB of 1500 bps.

SECTION 4

CONTROL SEGMENT OPERATIONS

The purpose of this section is to address the operation of the hardware and software described in the preceding section. To accomplish this purpose, the allocation of CS functions to personnel is examined first. Then, functional time lines are presented which bring the dimension of time to the functional allocations. To complete the section, the timelines are followed by a summary of the total staff--operational and support--requirements for the CS.

Effectively, then, this section describes the Control Segment operational concept and provides some models of operational activity within and among Segment elements. The discussion is for the most part applicable to Phase I operations only. An exception is paragraph 4.3, wherein estimated manning requirements are given for Phases IIA, IIB, and III.

4.1 FUNCTIONAL ALLOCATIONS

In Section 2 a number of CS functions are identified and allocated to the hardware, software and personnel resident at the CS stations. The baseline station configurations described in the preceding section are founded on the allocation of CS functions to hardware and software. The allocation of CS functions to personnel is examined below.

Table 4-1 establishes the functional allocations to personnel. Referring to the table, one notes that the CS staff is assigned the following tasks:

a. Initialize the segment operations and participate in recovery operations in the case of a segment outage.

b. Schedule segment operations

c. Supervise communications interfaces

d. Monitor segment status

e. Oversee upload operations

f. Calibrate the segment elements

g. Direct segment evaluation testing

TABLE 4-1
ALLOCATION OF CS FUNCTIONAL REQUIREMENTS TO CS PERSONNEL

FUNCTION	Master Control Station			Upload Station			Monitor Station			[illegible]
	HARDWARE CI NO 237273	SOFTWARE CPCI NO 237309	PERSONNEL	HARDWARE CI NO 237277	SOFTWARE CPCI NO 237313	PERSONNEL	HARDWARE CI NO 237275	SOFTWARE CPCI NO 237311	PERSONNEL	CI NO 237279
Control Segment Operations										
• Segment Initialization and Recovery		X	X			X				
• System Scheduling		X	X							
• Communications Function		X	X		X			X		X
• Display and Control Function	X	X		X	X		X	X		
• Status Monitoring Function	X	X	X	X	X	X	X	X		
Navigation Data Collection										
• System Calibration Data		X								
• Space Vehicle Tracking Data				X	X		X	X		
• System Time Standard	X	X								
• Space Vehicle Health and Status Data		X								
• Space Vehicle Access Key		X								
Navigation Data Processing										
• Tracking Data Preprocessing		X								
• Reference Ephemeris Generation		X								
• SV Ephemeris Prediction		X								
• SV Clock Prediction		X								
• Almanac Data Generation		X								
• Upload Message Generation		X								
Space Vehicle Navigation Subsystem Control										
• Navigation Upload Control		X	X		X	X				
• Upload Message Validation		X			X					
• Upload Message Transmission				X	X					
• Upload Verification and Retry				X	X					
System Test Calibration Maintenance										
• Control Segment Calibration				X		X	X		X	
• Ionospheric Data Collection		X								
• Navigation Performance Evaluation		X			X			X		
• Space Vehicle Signal Quality Monitoring				X	X					
• Support Software Development	X	X								
• Segment Readiness Testing	X	X		X	X		X	X		
• Segment Evaluation Testing	X	X	X	X	X		X	X		
• Logistics Support			X							

h. Provide logistics support

These tasks are assigned, in paragraph 4.3, to specific members of the CS staff. A brief discussion of each task is provided below.

Segment Initialization and Recovery

This task consists mainly of the loading of bootstrap computer programs to "bring up" the station(s) processor. In the case of a segment outage, this task enlarges to incorporate the coordination of segment-level troubleshooting; the loading, running and evaluation of software diagnostics and the re-establishment of the data bases that may have been lost due to a power failure or other contingent event.

Scheduling

This task is a book-keeping function supported by MCS software. For example, using space vehicle ETAs generated by the software, an upload schedule will be prepared and coordinated with US personnel. In addition to the scheduling of upload operations, this task will also address the scheduling of MCS contacts with the RCF. MCS contacts with the AFSCF, user equipment test periods, software development periods, preventive maintenance, station calibration, etc.

Communications

This task deals with the supervision of the communications function--principally the monitoring of the performance of the telecommunications network. For example, should an automatic dial-up fail to be completed it is within the scope of this task to troubleshoot the problem and correct it. Also within the scope of this task is the certification of billings for communication service.

Status Monitoring

This task is supported by CRT displays and software at both the MCS and US. The displays present system, segment and station performance data -- as an example see Figure 4-1 -- and these displays are evaluated as part of this task. If out-of-tolerance conditions are noted -- for example, a monitor station clock appears to be rapidly developing a significant bias -- more detailed status displays are requested, by keyboard entry. At the US, this task would encompass the monitoring of the upload process using a CRT display of such parameters as S-band transmitter power output, L-band receiver "carrier present" flags, upload message retransmission rate, S-band antenna pointing angles and/or deltas from commanded angles, etc.

Upload Control

As a companion task to the US status monitoring described above, MCS and US personnel will be responsible for overseeing the upload process which, without contingencies, is performed automatically under computer control. Within the scope of this task is the timely

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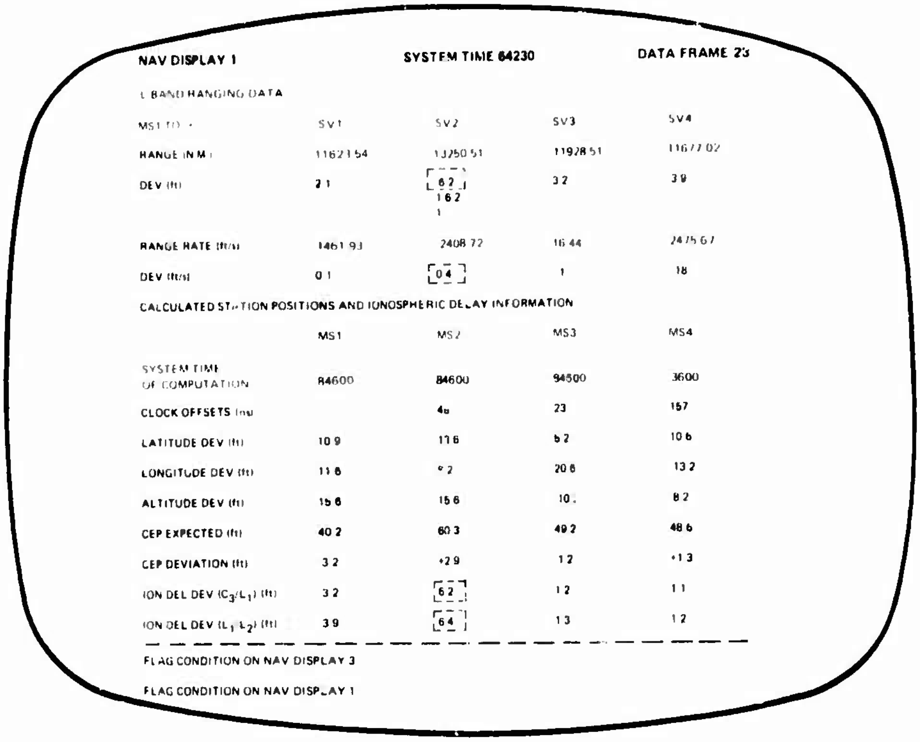


NAV DISPLAY 1 | SYSTEM TIME 64230 | DATA FRAME 23

L BAND RANGING DATA

MS1 TO →	SV1	SV2	SV3	SV4
RANGE (N M)	11621 54	13250 51	11928 51	11677 02
DEV (ft)	2 1	$\boxed{6 2}$ 16 2 1	3 2	3 9
RANGE RATE (ft/s)	1461 93	2408 72	16 44	2475 67
DEV (ft/s)	0 1	$\boxed{0 4}$	1	18

CALCULATED STATION POSITIONS AND IONOSPHERIC DELAY INFORMATION

	MS1	MS2	MS3	MS4
SYSTEM TIME OF COMPUTATION	84600	84600	94500	3600
CLOCK OFFSETS (ns)		46	23	157
LATITUDE DEV (ft)	10 9	11 6	5 2	10 6
LONGITUDE DEV (ft)	11 6	9 2	20 6	13 2
ALTITUDE DEV (ft)	15 6	15 6	10 .	8 2
CEP EXPECTED (ft)	40 2	60 3	49 2	48 6
CEP DEVIATION (ft)	3 2	+2 9	1 2	+1 3
ION DEL DEV (C_3/L_1) (ft)	3 2	$\boxed{6 2}$	1 2	1 1
ION DEL DEV (L_1/L_2) (ft)	3 9	$\boxed{6 4}$	1 3	1 2

FLAG CONDITION ON NAV DISPLAY 3

FLAG CONDITION ON NAV DISPLAY 1

Figure 4-1 Example of a NAV Analyst's CRT Format

implementation of the upload schedule, the inputting of any clear commands or navigation processor instructions that are not part of the pre-formatted upload message and the termination of an unsuccessful retransmission sequence.

Calibration

As an example of this function consider the calibration of the L-band receiving systems at the MS and US. It is important that the group delay from the L-band antenna to the receiver's code correlator be precisely known since this delay affects the location/coordinates of the US/MS, ie, any delay variation would create the appearance of station movement. Therefore, this group delay and other related parameters require periodic recalibration to maintain the integrity of the ephemeris determination process. This recalibration is beyond the capabilities of the stations' built-in test equipment so it must be performed by CS personnel.

Evaluation Testing

System readiness tests are performed automatically within each CS element. If, however, a readiness test reveals the inability of an element to provide mission support then performance testing must be initiated and directed by MCS personnel to isolate the failed or degraded component. This task is supported by hardware and software at all stations -- principally software diagnostic programs, programs to exercise built-in test equipment and the built-in test equipment itself.

Logistics Support

Whenever the performance evaluation testing identifies a failed or degraded component within the CS, personnel at the MCS must provide logistics support and replace or repair the faulty components. Therefore, MCS will manage stores of spare components, maintain a pool of test equipment and staff a maintenance facility.

4.2 FUNCTIONAL TIME LINES

This paragraph presents Phase I Control Segment operational functions in time line form. In this analysis activities and events associated with uploading have been emphasized, while most off-line functions, such as scheduling, analysis, and remote computation at NWL, have been omitted. Furthermore, only nominal operations are shown on the time lines. Anomalous events and conditions are discussed in paragraph 4.4, MCS Operations.

Figure 4-2 shows the Time-in View over the Upload Station for Phase I satellites, and functional time lines for the Master Control and Upload Stations during a typical 24-hour period. An expanded 120 minute time line of uploading activities just prior to the start of test time over Holloman AFB is also shown.

Figure 4-3 gives Phase I functional time lines for a typical 60-minute period at the Monitor Station.

Figures 4-4, 4-5, and 4-6 present bargraphs and associated tabulation of Satellite Times-in-View over the Upload Station for Phases IIA, IIB, III, respectively. These data are given assuming the Upload Station remains at Vandenberg Air Force Base. Figure 4-4 also shows an 8-hour shift period during which all nine Phase IIA satellites may be uploaded. It should be noted that for the Phase IIA Space Vehicle orbits used in this study, the upload period shown in Figure 4-4 coincides almost completely with the test time at Holloman AFB. This indicates that either the SV orbits or the current uploading ground rules will have to be revised as Phase IIA operational requirements are better defined. For Phase IIB uploading of all satellites cannot be accomplished during a single continuous 8-hour period; hence the requirement for a 10-hour period as shown in Figure 4-5.

Assuming a single upload location during Phase III, two shifts are required to upload 24 satellites, as shown in Figure 4-6.

4.3 MANNING REQUIREMENTS

This paragraph provides a summary of personnel required to operate and maintain the Ground Segment during Phase I, IIA, IIB, and III. The information provided only relates to the baseline configuration with impacts implied by alternative configurations to be discussed subsequently.

4.3.1 Assumptions

The following major assumptions have been made in providing the data contained in this paragraph:

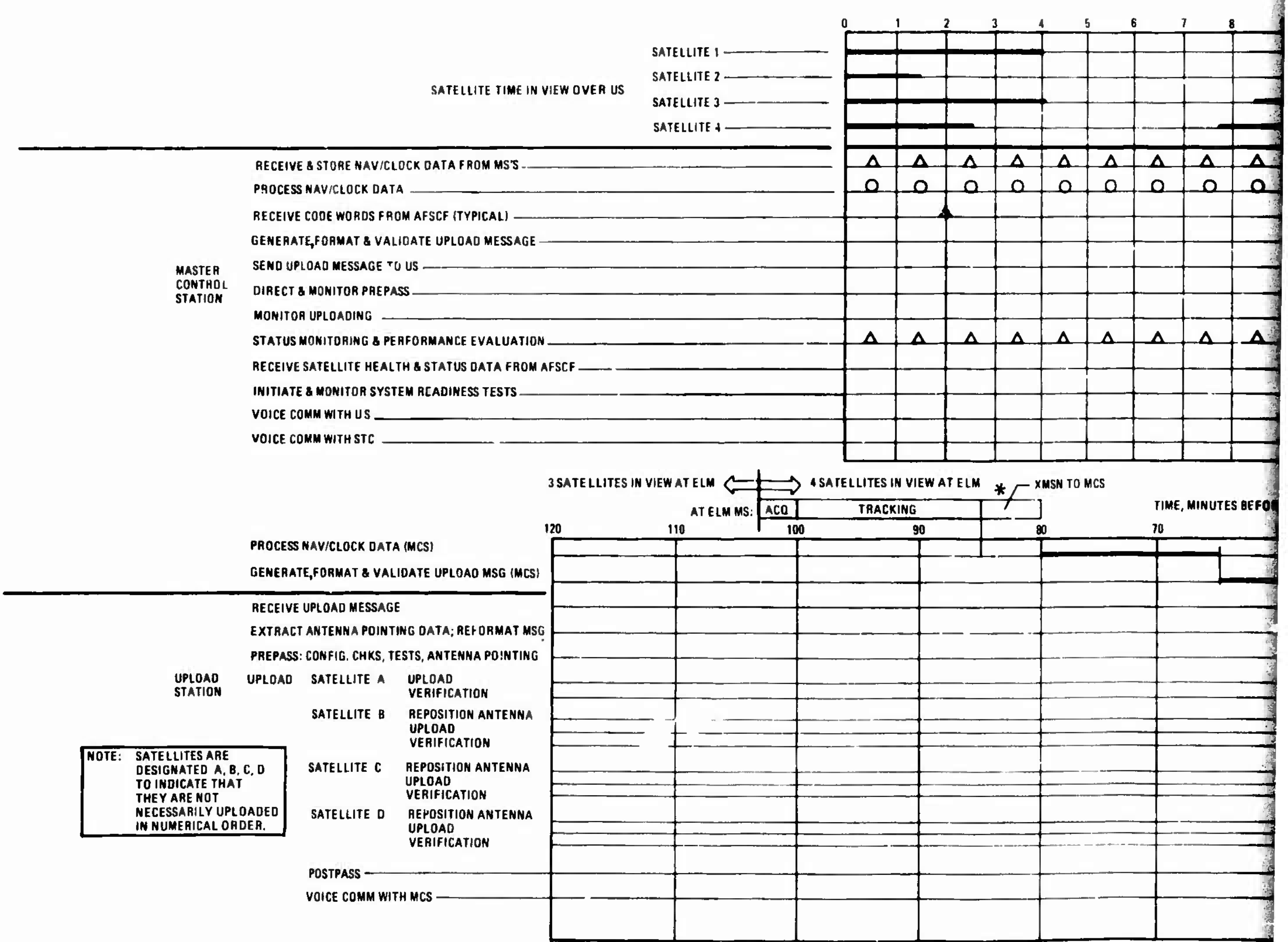
a. System testing will be done during Phase I and IIA and will be done on a 7-day per week, 1 shift per day basis. Hence the Master Control Station (MCS) and the Upload Station (US) will have to be manned on a comparable basis.

b. Phase IIB will be a transitional testing phase which will require a build-up of manning requirements to operational levels necessary during Phase III.

c. Phase III will be an operational phase and will require 24-hour per day, 7-day per week operational capability at both the MCS and the US.

d. Monitor Stations will operate on a 24-hour per day, 7-day per week basis during all phases.

e. Monitor Stations will not require any dedicated on-site manning.


0 1 2 3 4 5 6 7 8
SATELLITE TIME IN VIEW OVER US
SATELLITE 1
SATELLITE 2
SATELLITE 3
SATELLITE 4
MASTER CONTROL STATION
RECEIVE & STORE NAV/CLOCK DATA FROM MS'S
PROCESS NAV/CLOCK DATA
RECEIVE CODE WORDS FROM AFSCF (TYPICAL)
GENERATE,FORMAT & VALIDATE UPLOAD MESSAGE
SEND UPLOAD MESSAGE TO US
DIRECT & MONITOR PREPASS
MONITOR UPLOADING
STATUS MONITORING & PERFORMANCE EVALUATION
RECEIVE SATELLITE HEALTH & STATUS DATA FROM AFSCF
INITIATE & MONITOR SYSTEM READINESS TESTS
VOICE COMM WITH US
VOICE COMM WITH STC
3 SATELLITES IN VIEW AT ELM
4 SATELLITES IN VIEW AT ELM
* XMSN TO MCS
AT ELM MS: ACQ TRACKING
TIME, MINUTES BEFO
120 110 100 90 80 70
PROCESS NAV/CLOCK DATA (MCS)
GENERATE,FORMAT & VALIDATE UPLOAD MSG (MCS)
UPLOAD STATION
RECEIVE UPLOAD MESSAGE
EXTRACT ANTENNA POINTING DATA; REFORMAT MSG
PREPASS: CONFIG. CHKS, TESTS, ANTENNA POINTING
UPLOAD
SATELLITE A UPLOAD VERIFICATION
SATELLITE B REPOSITION ANTENNA UPLOAD VERIFICATION
SATELLITE C REPOSITION ANTENNA UPLOAD VERIFICATION
SATELLITE D REPOSITION ANTENNA UPLOAD VERIFICATION
POSTPASS
VOICE COMM WITH MCS
NOTE: SATELLITES ARE DESIGNATED A, B, C, D TO INDICATE THAT THEY ARE NOT NECESSARILY UPLOADED IN NUMERICAL ORDER.

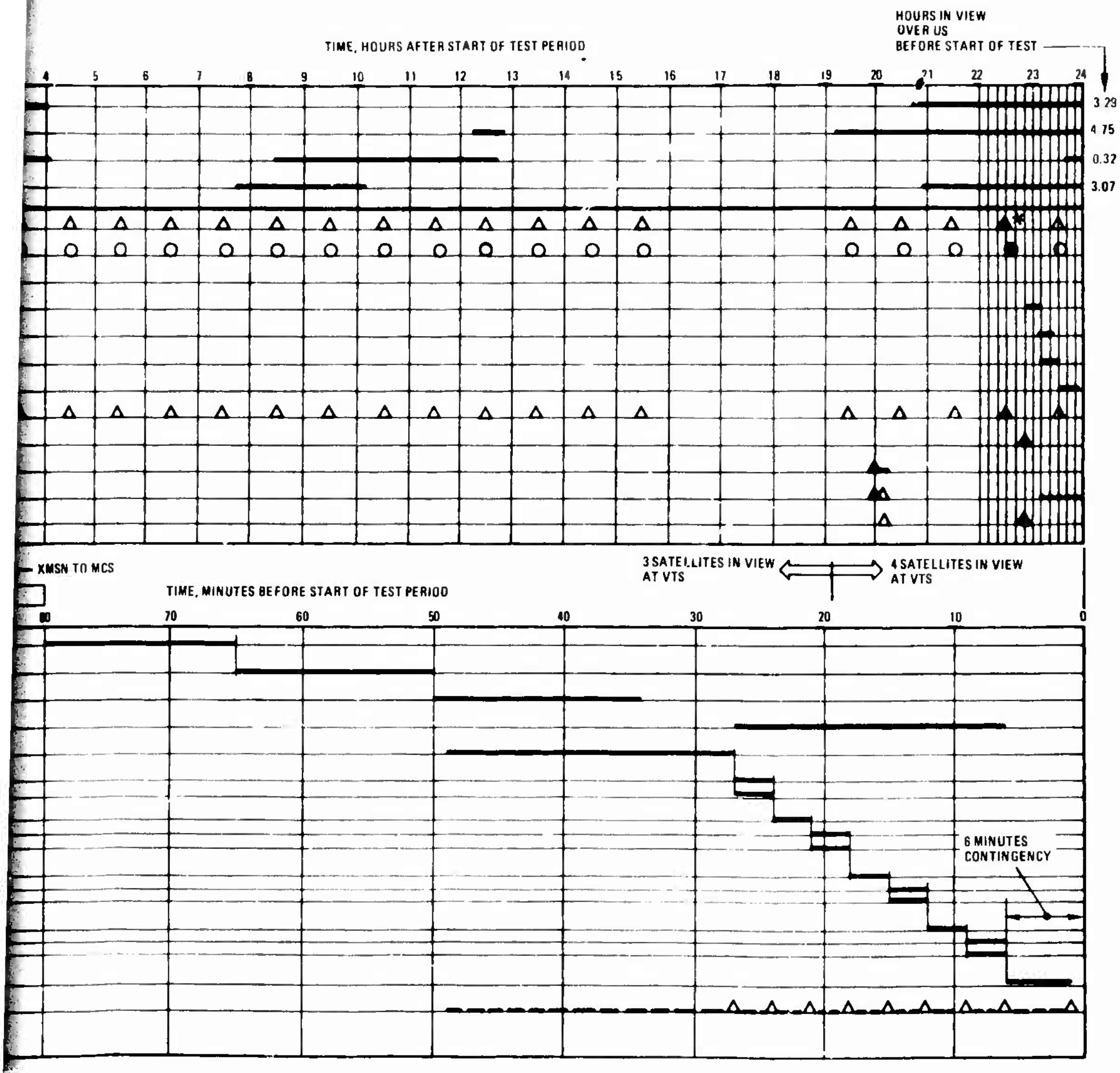


Figure 4-2 Functional Timelines for MCS and US (Phase I)

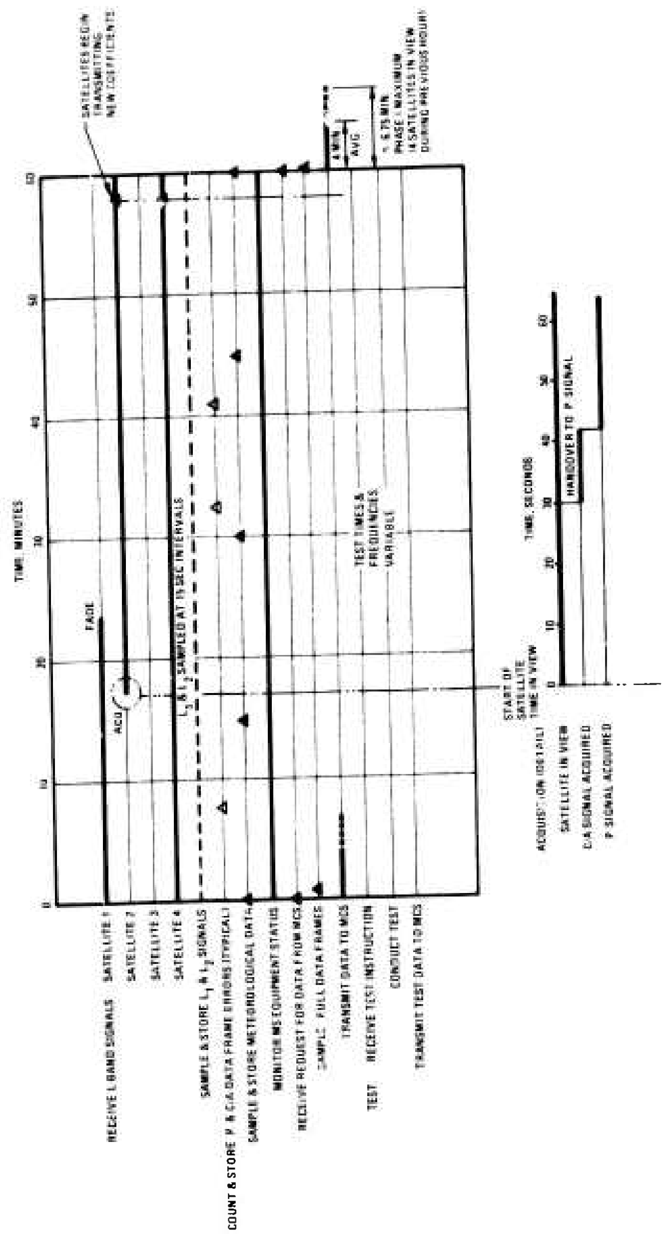


Figure 4-3 Functional Timelines for Monitor Station (Phase I)

ORBIT CONFIGURATION= OMEGA-2A
SATELLITE VIEW PERIODS AT VTS
ELEVATION ANGLE GREATER THAN: 5 DEG

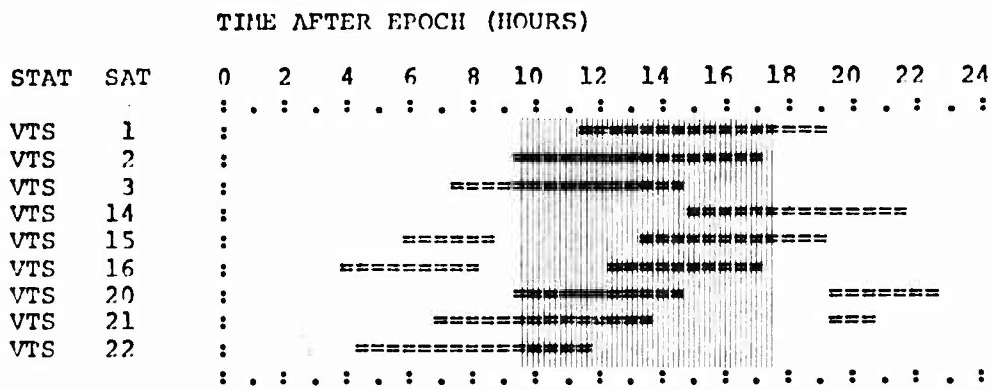


TABLE OF VIEW PERIODS (HOURS AFTER EPOCH)

STAT	SAT	RISE	SET	RISE	SET	RISE	SET	TOT IN	TOT OUT	MAX OUT SEGMENT
VTS	1	11.60	19.08	.00	.00	.00	.00	7.48	16.52	16.517
VTS	2	9.43	17.05	.00	.00	.00	.00	7.62	16.38	16.383
VTS	3	7.65	14.45	.00	.00	.00	.00	6.80	17.20	17.200
VTS	14	15.08	21.50	.00	.00	.00	.00	6.42	17.58	17.583
VTS	15	5.97	8.62	13.63	19.10	.00	.00	8.12	15.88	10.867
VTS	16	4.08	8.08	12.47	17.08	.00	.00	8.62	15.38	11.000
VTS	20	9.48	14.73	19.52	22.57	.00	.00	8.30	15.70	10.917
VTS	21	7.22	13.35	19.38	20.50	.00	.00	7.25	16.75	10.717
VTS	22	4.48	11.72	.00	.00	.00	.00	7.23	16.77	16.767

Figure 4-4 Phase II A Satellite Times-In-View Over Upload Station at Vandenberg AFB Showing A Possible Upload "Window"

ORBIT CONFIGURATION= GAMMA-2B
SATELLITE VIEW PERIODS AT VTS
ELEVATION ANGLE GREATER THAN: 5 DEG

TIME AFTER EPOCH (HOURS)

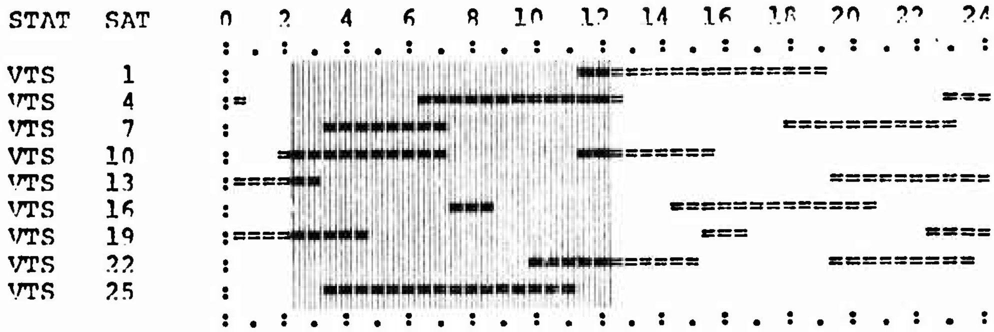


TABLE OF VIEW PERIODS (HOURS AFTER EPOCH)

STAT	SAT	RISE	SET	RISE	SET	RISE	SET	TOT IN	TOT OUT	MAX OUT SEGMENT
VTS	1	11.65	19.17	.00	.00	.00	.00	7.52	16.48	16.483
VTS	4	.00	.68	6.62	12.72	23.23	24.00	7.55	16.45	10.517
VTS	7	3.73	7.25	18.20	23.15	.00	.00	8.47	15.53	10.050
VTS	10	2.18	7.17	11.72	15.27	.00	.00	8.53	15.47	10.917
VTS	13	.00	3.15	19.67	24.00	.00	.00	7.48	16.52	16.517
VTS	16	7.38	8.67	14.62	20.72	.00	.00	7.38	16.62	10.667
VTS	19	.00	4.70	15.40	16.63	22.62	24.00	7.32	16.68	10.700
VTS	22	10.18	15.17	19.70	23.27	.00	.00	8.55	15.45	10.917
VTS	25	3.63	11.15	.00	.00	.00	.00	7.52	16.48	16.483

Figure 4-5 Phase II B Satellite Times-In-View Over Upload Station at Vandenberg AFB Showing a 10-Hour Upload "Window"

PHILCO Ford
Philco-Ford Corporation
Western Development Laboratories Division

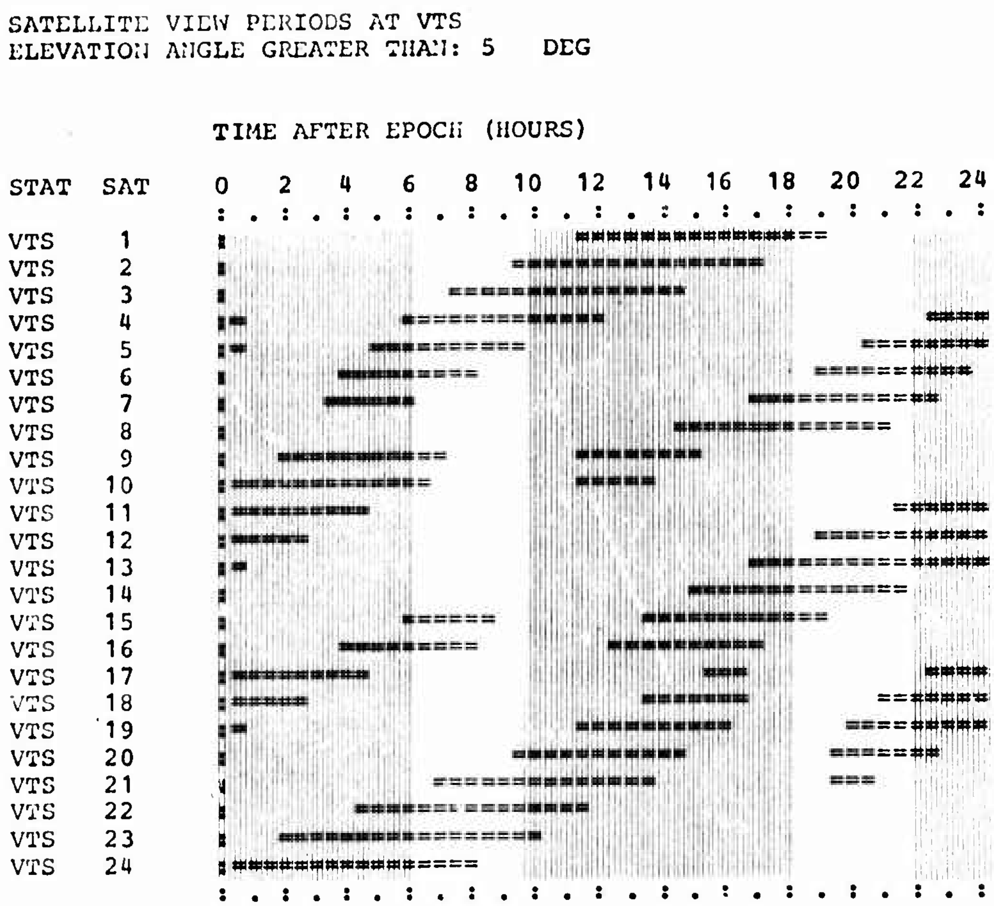


Figure 4-6 Phase III Satellite Times-In-View Over Upload Station at Vandenberg AFB Showing Two 8-Hour Upload "Windows"

f. The MCS will require a 24-hour per day, 7-day per week system monitoring and data analysis capability during Phases I and IIA. (This function will be assumed by operational personnel during Phases IIB and III).

g. The MCS and US will be collocated in the Prelort Building (or equivalent) at Vandenberg Tracking Station, VAFB.

h. Although the US will be designed for relocation, the manning levels shown in the enclosed tables reflect the ability to "share" personnel between the US and the MCS. Notations have been made to identify increases necessary if this "sharing" is not feasible due to subsequent physical separation of the MCS and US.

i. Manning quantities shown for basic coverage and for contingency augmentation reflect typical shift practices and the level of losses expected for military or civil service personnel.

j. Each man will work only 5 days (40 hours) per week and overtime normally will not be authorized.

k. Each satellite will be uploaded only once a day.

l. Uploading during Phases I and IIA can and will be performed within the time-frame of a single 8-hour shift. (Uploading during Phases IIB and III need not be limited to single shift, since 24-hour per day, 7-day per week operational manning will be provided. See assumptions b and c above.)

4.3.2 Manning Levels

Table 4-2 provides a list of personnel required for operation and maintenance of the GPS. In addition to position titles, this table provides a general statement regarding the operating location of the individual, his general responsibilities, the shift coverage necessary for the position (5 days a week versus 7 days a week, 8 hours per day versus 24 hours per day, etc.), and the number of personnel required for each position both on a per shift and a total basis.

The quantities of personnel shown include augmentation for sickness, vacation, and other absences and no additional personnel are required for augmentation.

In addition to the definition of manning requirements in Table 4-2, a typical shift schedule is provided in Table 4-3 which could be used for each of the positions specified during Phases I and IIA. Table 4-4 shows a typical shift schedule applicable to Phases IIB and III.

TABLE 4-2

VANDENBERG MASTER CONTROL STATION/UPLOAD STATION PERSONNEL REQUIREMENTS

POSITION TITLE AND OPERATING LOCATION	QUANTITY REQUIRED								SHIFTING	POSITION RESPONSIBILITIES
	PHASE I		PHASE IIA		PHASE IIB		PHASE III			
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)		
1. <u>GPS OPERATIONS/MAINTENANCE SUPERVISOR</u> (No operational responsibilities. Requires office space.)	1	1	1	1	1	1	1	1	5 days per week, 1 shift per day, during all phases	a. Has responsibility for all operations and maintenance acitvities at the MCS and the ULS. b. Provides technical guidance to ops/maintenance personnel. c. Handles interface contacts with SCF and NAG organizations.
2. <u>CLERK/TYPIST</u> (Requires desk space.)	1	1	1	1	1	1	1	1	5 days per week, 1 shift per day, during all phases	a. Performs normal clerical duties of typing, filing, report preparation, and record maintenance.

(1) = PER SHIFT REQUIREMENTS
(2) = TOTAL REQUIREMENTS FOR POSITION SPECIFIED

TABLE 4-2(CONT'D)

VANDENBERG MASTER CONTROL STATION/UPLOAD STATION PERSONNEL REQUIREMENTS

POSITION TITLE AND OPERATING LOCATION	QUANTITY REQUIRED								SHIFTING	POSITION RESPONSIBILITIES
	PHASE I		PHASE IIA		PHASE IIB		PHASE III			
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)		
3. SENIOR OPERATIONS CONTROLLER/OPERSTIONS CONTROLLER (Operates/controls from System Control Console. Sr. Ops Controller requires desk space, as well).	1	2	1	2	1	5	1	5	7 days per week, 1 shift per day, during Phases I and IIA. 7 days per week, 3 shifts per day during Phases IIB and III.	a. Provides direct supervision of MCS personnel. b. Performs regular SCF coordination and scheduling. c. Provides ops planning and ULS/MCS shceduling. d. Handles comm control for both the ULS and the SCF. e. Coordinates upload with upload station through direct voice contact. f. Provides system status monitoring and fault detection. g. Validates upload results. h. Monitors telemetry data. i. Directs/conducts system readiness tests.
4. NAVIGATION/EPHEMERIS DATA AND PERFORMANCE ANALYST (Monitors from System Control Console for real-time data analysis. Requires desk space for off-line analysis work.).	1	2	1	2	1	5	1	5	7 days per week, 1 shift per day, during Phases I and IIA. 7 days per week, 3 shifts per day during Phases IIB and III.	a. Conducts performance evaluation. b. Initiates upload preparation. c. Performs real-time data analysis and decision-making, as required.

(1) = PER SHIFT REQUIREMENTS
(2) = TOTAL REQUIREMENTS FOR POSITION SPECIFIED

TABLE 4-2 (CONT'D)

VANDENBERG MASTER CONTROL STATION/UPLOAD STATION PERSONNEL REQUIREMENTS

POSITION TITLE AND OPERATING LOCATION	QUANTITY REQUIRED								SHIFTING	POSITION RESPONSIBILITIES
	PHASE I		PHASE IIA		PHASE IIB		PHASE III			
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)		
5. DIGITAL EQUIPMENT TECHNICIAN (Primary operating location is the MCS Computer equipment.)	1	2	1	2	1	5	1	5	7 days per week, 1 shift per day, during Phases I and IIA. 7 days per week, 3 shifts per day during Phases IIB and III.	a. Operates and maintains MCS computer equipment. b. Maintains MCS display and timing equipment. c. Maintains digital equipment in the Upload Station during time when ULS and MCS are co-located at Vandenberg. d. Provides on-call maintenance support during off-duty hours.
6. SYSTEM MONITOR/ANALYST (Primary monitoring location is the MCS Computer equipment.)	1	4	1	4	0	0	0	0	7 days per week, 2nd and 3rd shift coverage during Phase I and IIA. (Coverage during Phases IIB and III is provided by other positions.)	a. Provides 2nd and 3rd shift system monitoring. b. Analyzes data from monitor stations to identify major malfunctions at monitor stations. c. Responsible for recall of ops/maintenance personnel, as required,
7. SYSTEM ANALYST (Requires off-line desk space for data analysis. No operational responsibilities.)	2	2	2	2	2	2	2	2	5 day per week, 1 shift per day.	a. Performs non-real-time, off-line data analysis. b. Evaluates system hardware and software performance. c. Determines potentially anomalous situations and coordinates corrective actions with Ops Controller and Nav./Ephem. Analyst.

(1) = PER SHIFT REQUIREMENTS
(2) = TOTAL REQUIREMENTS FOR POSITION SPECIFIED

TABLE 4-2 (CONT'D)

VANDENBERG MASTER CONTROL STATION/UPLOAD STATION PERSONNEL REQUIREMENTS

POSITION TITLE AND OPERATING LOCATION	QUANTITY REQUIRED PHASE I (1)	PHASE I (2)	PHASE IIA (1)	PHASE IIA (2)	PHASE IIB (1)	PHASE IIB (2)	PHASE III (1)	PHASE III (2)	SHIFTING	POSITION RESPONSIBILITIES
8. MONITOR STATION <u>MAINTENANCE TECHNICIAN</u> (No operational responsibilities. Requires work bench area.)	1	1	1	1	1	1	1	1	5 days per week, 1 shift per day.	a. Dispatches replacement chassis to Monitor Stations upon notification of malfunction. b. Repairs chassis which have been returned from the Monitor Stations. c. Provides preventive and corrective maintenance support for Vandenberg Monitor Station.
9. UPLOAD STATION <u>TECHNICIAN</u> (Operates/monitors XMTR/RCVR/Computer equipment.)	1*	2*	1*	2*	1*	5*	1*	5*	7 days per week, 1 shift per day, during Phases I and IIA. 7 days per week, 3 shifts per day during Phases IIB and III.	a. Sets up/operates/monitors RCVR/XMTR/Computer equipment. b. Performs preventive/corrective maintenance on RCVR/XMTR equipment. c. Monitors/conducts system tests to insure operational readiness. d. Insures command message is correct.
TOTAL REQUIREMENTS DAY SHIFT	9	17	9	1[illegible]	9	25	9	25		
TOTAL REQUIREMENTS 2ND, 3RD SHIFTS	1		1		4		4			

(1) = PER SHIFT REQUIREMENTS
(2) = TOTAL REQUIREMENTS FOR POSITION SPECIFIED

* If and when the ULS and MCS are <u>not</u> co-located, each of these numbers will <u>double</u> to allow for inclusion of digital maintenance, administration, supervision, and safety considerations.

TABLE 4-3

TYPICAL WEEKLY WORK SCHEDULE - PHASES I AND IIA

MASTER CONTROL STATION/UPLOAD STATION - VANDENBERG AIR FORCE BASE	WORK SCHEDULE S	M	T	W	T	F	S
GPS OPERATIONS/MAINTENANCE SUPERVISOR	O	X	X	X	X	X	O
CLERK/TYPIST	O	X	X	X	X	X	O
SENIOR OPERATIONS CONTROLLER	O	X	X	X	X	X	O
OPERATIONS CONTROLLER	X	O	O	X	X	X	X
#1 NAVIGATION/EPHEMERIS DATA/PERF. ANALYST	X	X	X	X	X	O	C
#2 NAVIGATION/EPHEMERIS DATA/PERF. ANALYST	X	X	X	O	O	X	X
#1 DIGITAL EQUIPMENT TECHNICIAN	X	X	X	O	O	X	X
#2 DIGITAL EQUIPMENT TECHNICIAN	O	O	X	X	X	X	X
#1 2ND SHIFT SYSTEM MONITOR/ANALYST	O	X	X	X	X	X	O
#2 2ND SHIFT SYSTEM MONITOR/ANALYST	X	O	O	X	X	X	X
#1 3RD SHIFT SYSTEM MONITOR/ANALYST	O	X	X	X	X	X	O
#2 3RD SHIFT SYSTEM MONITOR/ANALYST	X	X	X	X	O	O	X
#1 SYSTEM ANALYST	O	X	X	X	X	X	O
#2 SYSTEM ANALYST	O	X	X	X	X	X	O
MONITOR STATION MAINTENANCE TECHNICIAN	O	X	X	X	X	X	O
#1 US TECHNICIAN	X	X	X	X	X	O	O
#2 US TECHNICIAN	X	X	O	O	X	X	X

X = ON-DUTY DAY

O = DAY OFF

TABLE 4-4

TYPICAL WEEKLY WORK SCHEDULE - PHASES IIB AND III BASELINE

POSITION NUMBER *	S	M	T	W	T	F	S
	WORK SCHEDULE						
MAN #1	O	D	D	D	D	D	O
MAN #2	S	O	O	S	S	S	S
MAN #3	D	S	S	O	O	D	D
MAN #4	M	D	D	D	O	O	M
MAN #5	O	M	M	M	M	M	O

D = DAY SHIFT (0800 TO 1600, e.g.)

S = SWING SHIFT (1600 TO 2400, e.g.)

M = MIDNIGHT SHIFT (0000 TO 0800, e.g.)

O = OFF-DUTY

SHIFT	S	M	T	W	T	F	S
	NUMBER OF PERSONNEL ON-DUTY/ OFF-DUTY PER POSITION						
DAY	1	2	2	2	1	2	1
SWING	1	1	1	1	1	1	1
MIDNIGHT	1	1	1	1	1	1	1
OFF-DUTY	2	1	1	1	2	1	2
TOTAL	5	5	5	5	5	5	5

* This applies to all positions at both the MCS and the US requiring 5 people per position to fill 24 hour per day, 7 day per week requirements. Specifically this schedule applies to the Senior Ops Controller/Ops Controller, Navigation/Ephemeris Data/Performance Analyst, Digital Equipment Technician, and US Technician.

4.3.3 Other Personnel Requirements

The personnel detailed in Table 4-2 are intended to be fully dedicated to the GPS program and would not be assigned operational/maintenance/analysis duties with other programs. There are, however, certain functions at the MCS/US and the Monitor Stations which require less than full-time personnel commitment. These functions may be assumable by existing Host Base personnel, but in any event should be addressed in any cost considerations.

Specifically, the following functions may be assumable by existing personnel:

1. Antenna and servo maintenance at the US.

2. Remove and replace actions at the various Monitor Stations (other than Vandenberg.)

3. Facilities support at all locations (as noted in paragraph 3.2).

The manning budget for the CS, derived above, provides for full and flexible GPS operation through all phases. The Phase I manning considers the legacy of on-the-job-training and therefore may introduce a level of manning somewhat above "bare minimums". With this point in view, and noting the fact that the leading assumptions are yet to be negotiated, it is possible that initial GPS manning could be structured downward with an attendant loss of flexibility and legacy.

4.4 MCS OPERATIONS

This paragraph provides an activity model of operations at the Master Control Station. While this model has been developed for Phase I operations, it is considered to be largely applicable to subsequent Phases. In Phases II and III the volume of activity within the Ground Segment will increase significantly, but it is felt that the basic operational concept will probably be little changed.

The MCS operational model is presented in a series of decision/action diagrams. These diagrams show both normal as well as some anomalous or abnormal situations which may be encountered during MCS operations. Various types of decisions, actions, frequencies, and events are represented by a repertoire of graphic symbols.

Assumptions

1. The activity model presented here ignores the fact that the Upload Station is collocated with the Master Control in the baseline Control Segment Configuration. This reflects the requirement that the Upload Station be "transportable".

2. SV access code words are loaded by the AFSCF, and stored aboard the SV. Several days worth of code words is sent from STC to MCS (in a secure off-line mode, eg, courier). MCS to

US transfer is no problem while MCS and US are collocated (if and when the US is remoted from MCS, the problem of secure transmission of code words will be addressed at that time). SV "unlock" and "lockup" words are sent at the beginning and end of upload transmission. Each word is sent in the clear and used only once. At the end of the upload message the SV shifts to the next "unlock" word in storage, i.e., the first word of the next upload transmission.

3. The time at which SV's switch over to the transmission of new position coefficients is the same time for all SV's.

4. Back-up uploading by the AFSCF does not take place in a time-critical operational environment during Phase I. If normal uploading by the Control Segment is not possible (or if a test of back-up uploading is desired), AFSCF support is scheduled according to:

   - Time factors (how long until next test period)

   - AFSCF availability in the context of priorities previously negotiated between the GPS and the AFSCF.

Figure 4-7 is the decision/action diagram for the Master Control and Upload Stations, with Monitor Station, AFSCF and RCF interfaces shown. In additional to presenting nominal Control Segment operations, this diagram shows the operational flow associated with back uploading. Some salient features of operational activity in the MCS are:

a. Estimation of SV ephemerides and clock parameters are computed hourly whenever Monitor Station data are available. Predictions of SV ephemerides and clock parameters are computed once a day as required for uploading.

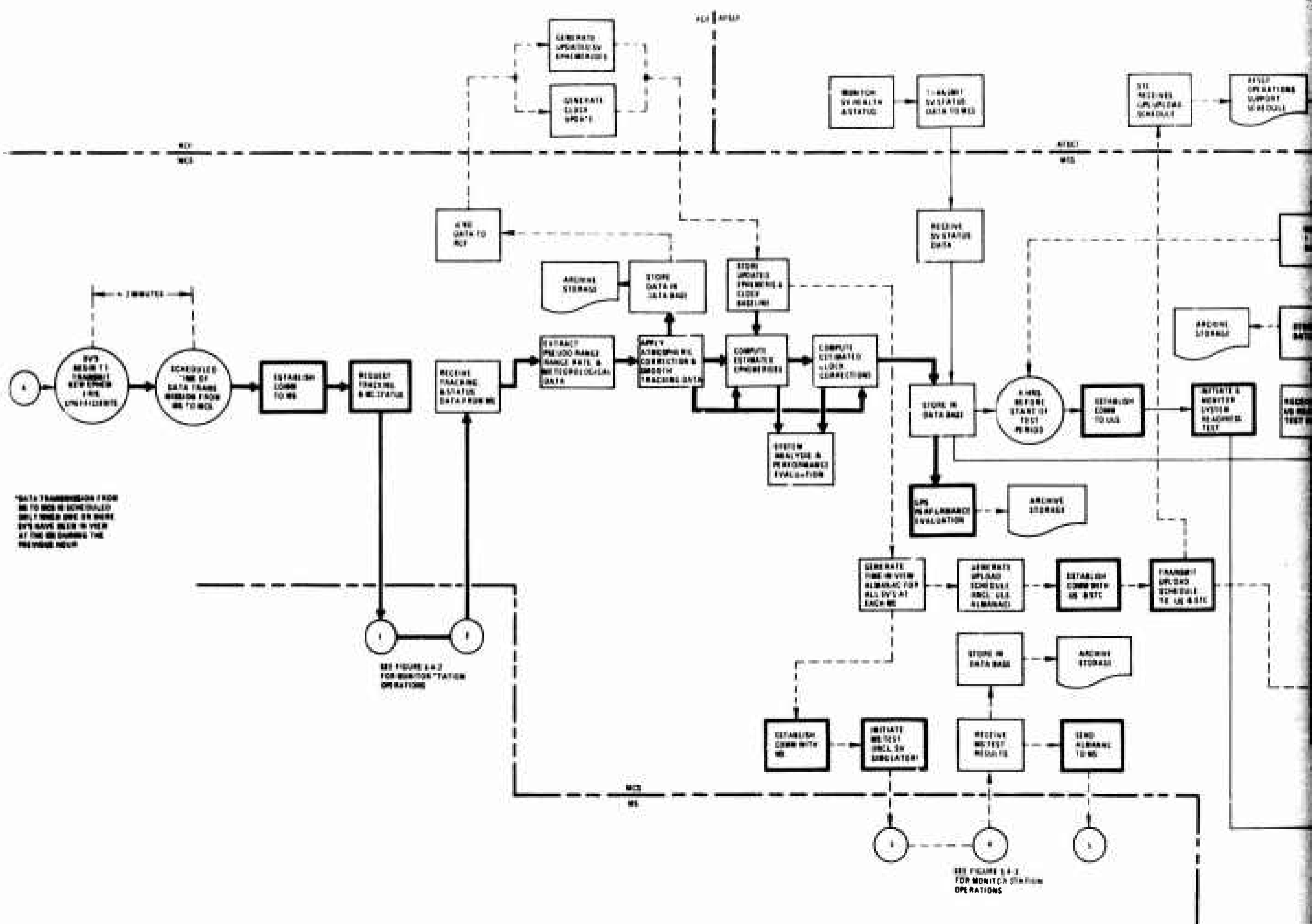
b. System readiness tests are normally conducted twice a day. The first test occurs about four hours before the start of the test period over Holloman AFB. This test is conducted to determine whether AFSCF support will be required for backup uploading. If normal uploading is available a second readiness test is conducted as the prepass test at the Upload Station.

c. Loop testing involving the Built-in Test Equipment (BITE) at the Monitor Station will be conducted once a week and will coincide with the transmission of the SV almanac to the MS.

d. In Phase I, Master Control will poll all Monitor Stations for data at the same time. The specific time will be selected to occur several minutes after the SV's begin transmitting new position coefficients. This is done to permit early validation of the new coefficients.

Figure 4-8 is the operational decision/action diagram for the Monitor Station, showing MCS interfaces.

Figure 4-9 shows the decision/action flow for a typical anomalous situation; one in which an out-of-tolerance condition in clock parameters has been detected.



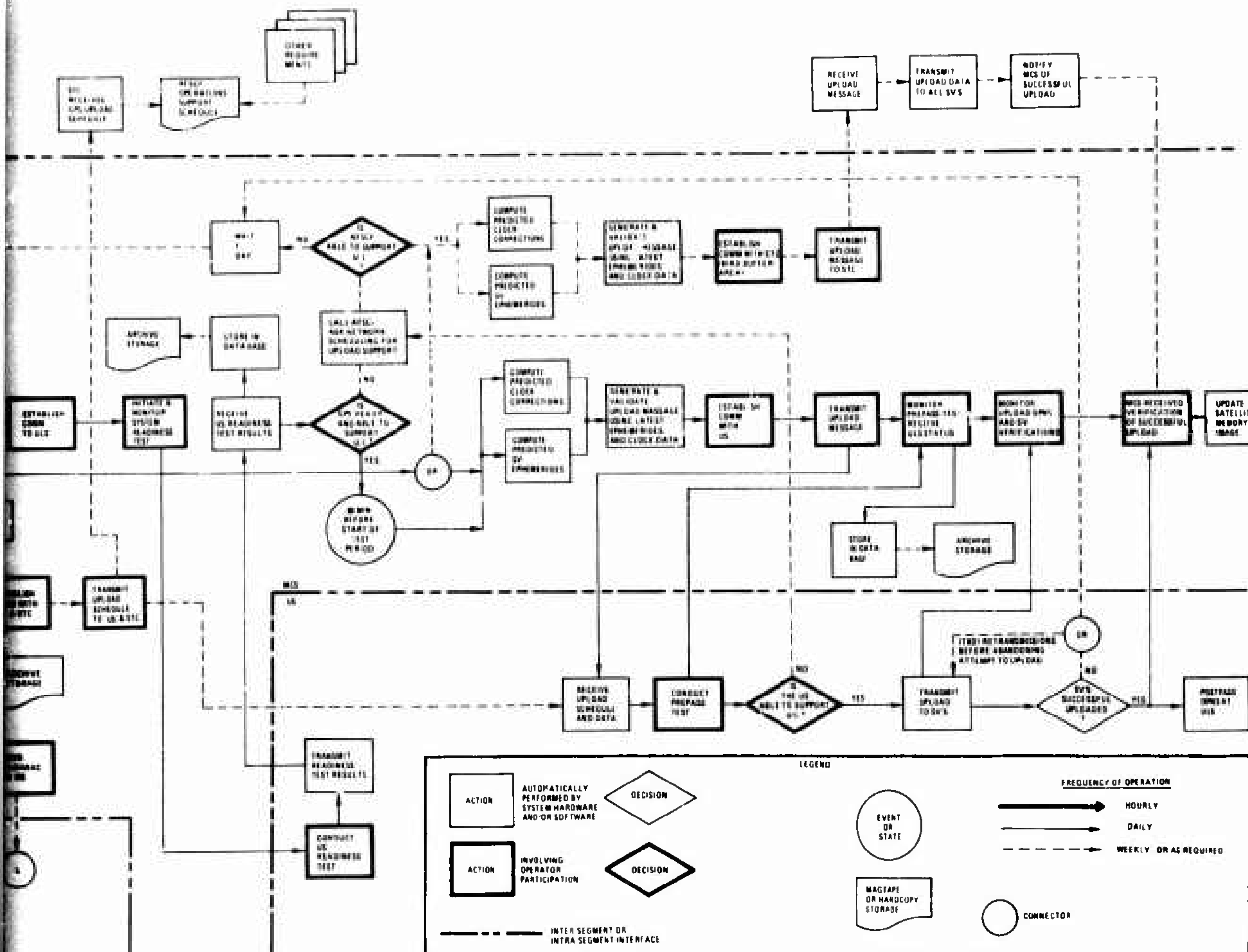
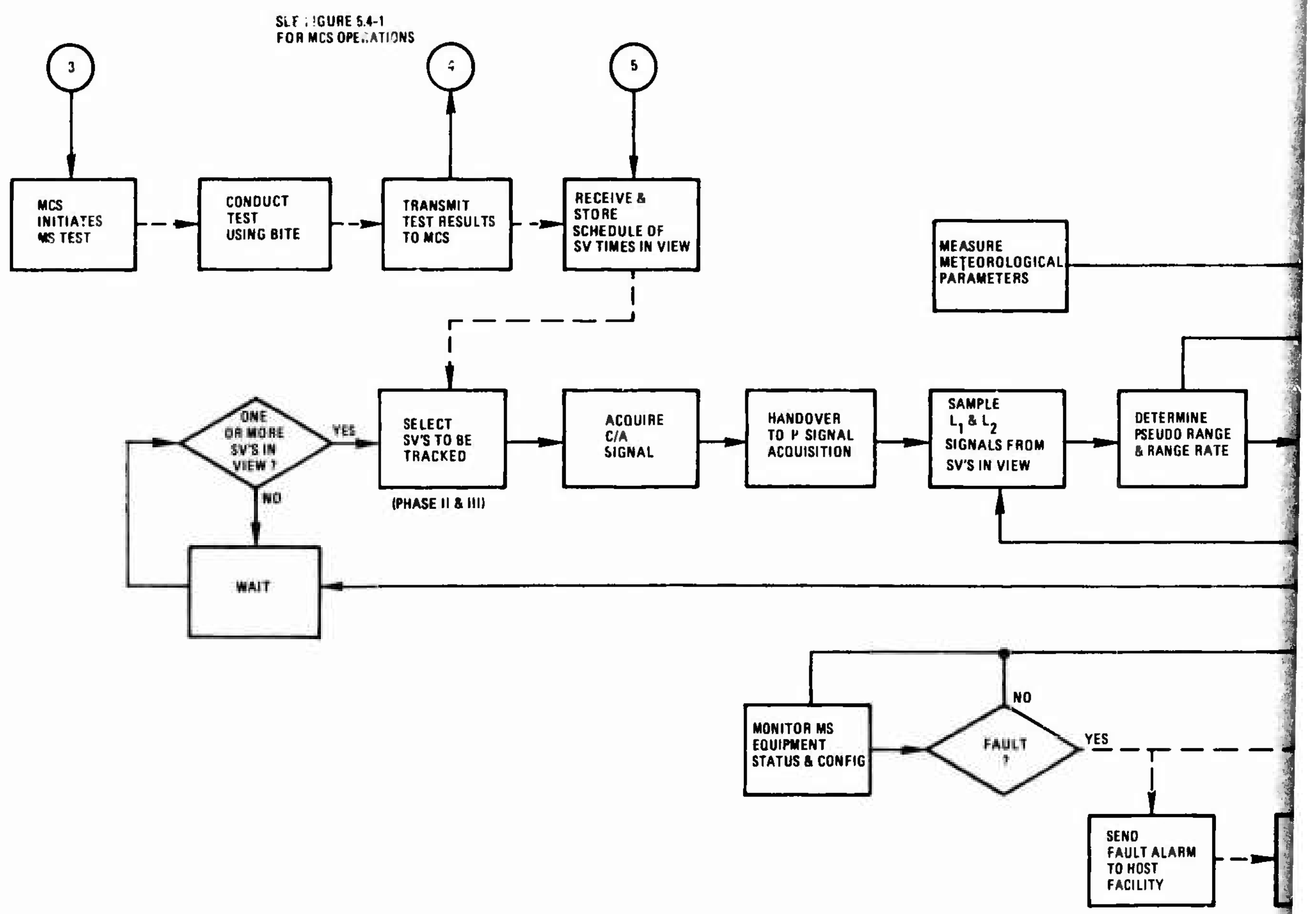


Figure 4-7 Decision/Action Diagram for Master Control Station and Upload Station (Phase I)


SEE FIGURE 5.4-1
FOR MCS OPERATIONS
3
4
5
MCS INITIATES MS TEST
CONDUCT TEST USING BITE
TRANSMIT TEST RESULTS TO MCS
RECEIVE & STORE SCHEDULE OF SV TIMES IN VIEW
MEASURE METEOROLOGICAL PARAMETERS
ONE OR MORE SV'S IN VIEW ?
YES
NO
SELECT SV'S TO BE TRACKED
(PHASE II & III)
ACQUIRE C/A SIGNAL
HANDOVER TO P SIGNAL ACQUISITION
SAMPLE L_1 & L_2 SIGNALS FROM SV'S IN VIEW
DETERMINE PSEUDO RANGE & RANGE RATE
WAIT
MONITOR MS EQUIPMENT STATUS & CONFIG
FAULT ?
NO
YES
SEND FAULT ALARM TO HOST FACILITY

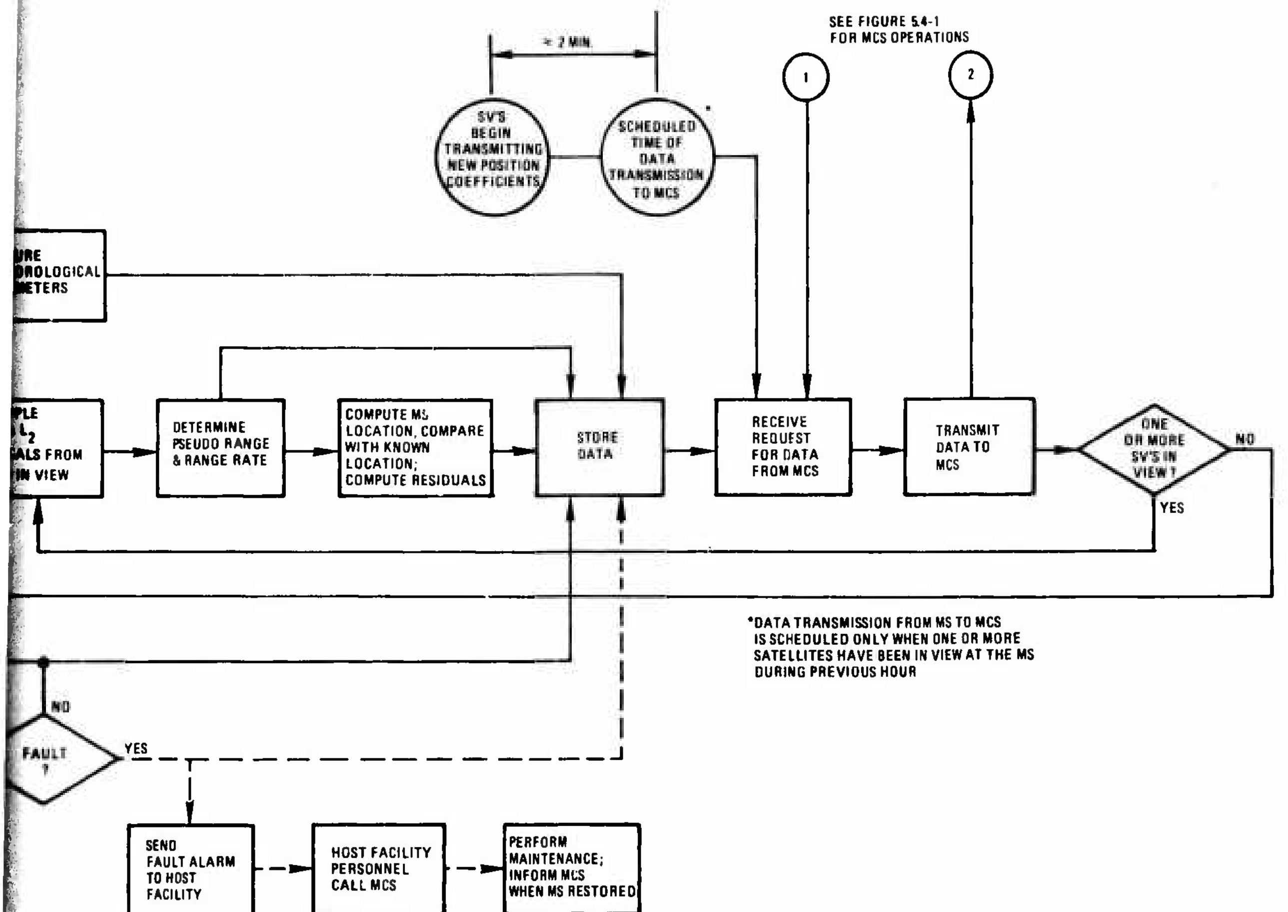
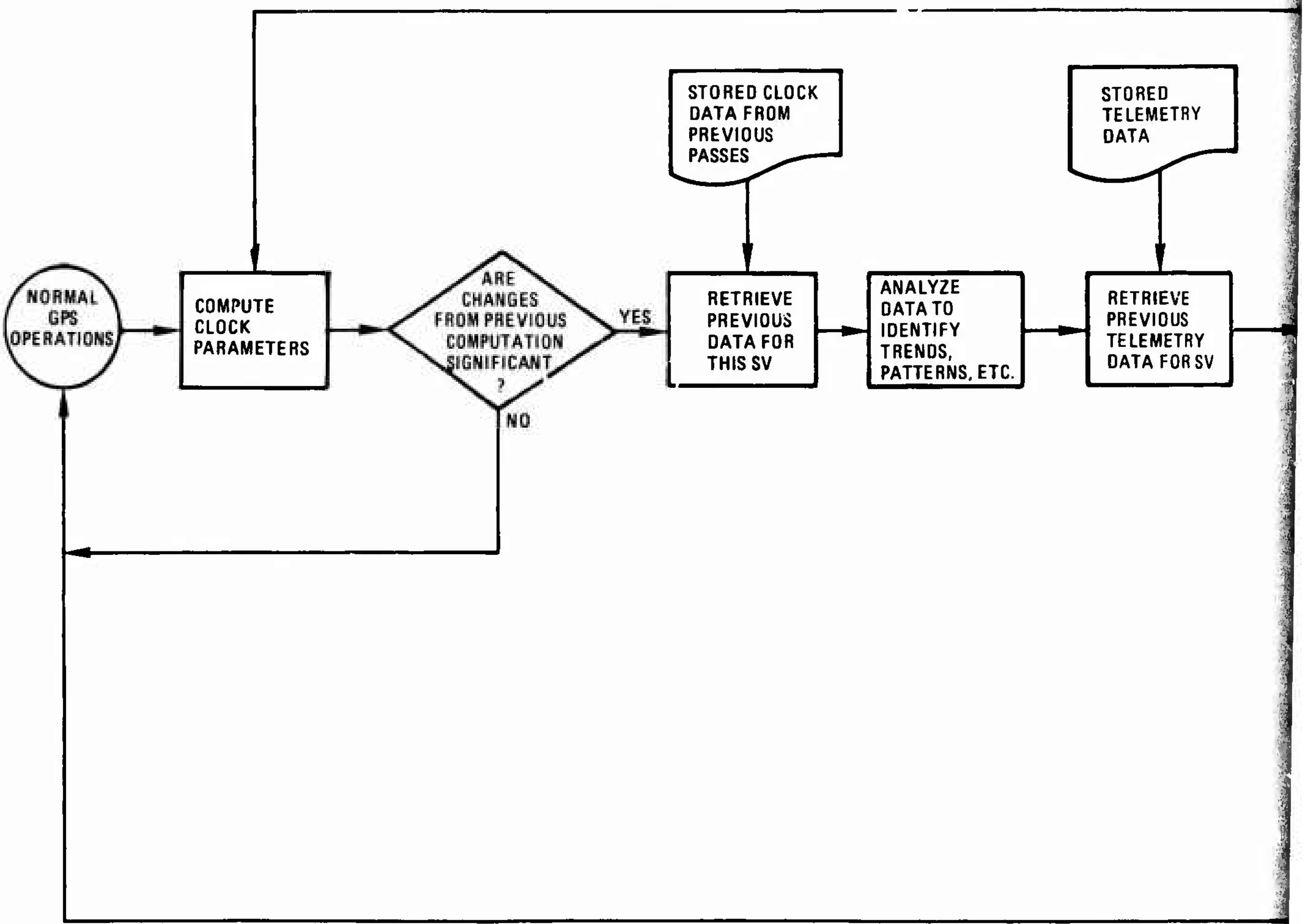


Figure 4-8 Decision/Action Diagram for Monitor Station (Phase I)


NORMAL GPS OPERATIONS
COMPUTE CLOCK PARAMETERS
ARE CHANGES FROM PREVIOUS COMPUTATION SIGNIFICANT ?
YES
NO
STORED CLOCK DATA FROM PREVIOUS PASSES
RETRIEVE PREVIOUS DATA FOR THIS SV
ANALYZE DATA TO IDENTIFY TRENDS, PATTERNS, ETC.
STORED TELEMETRY DATA
RETRIEVE PREVIOUS TELEMETRY DATA FOR SV

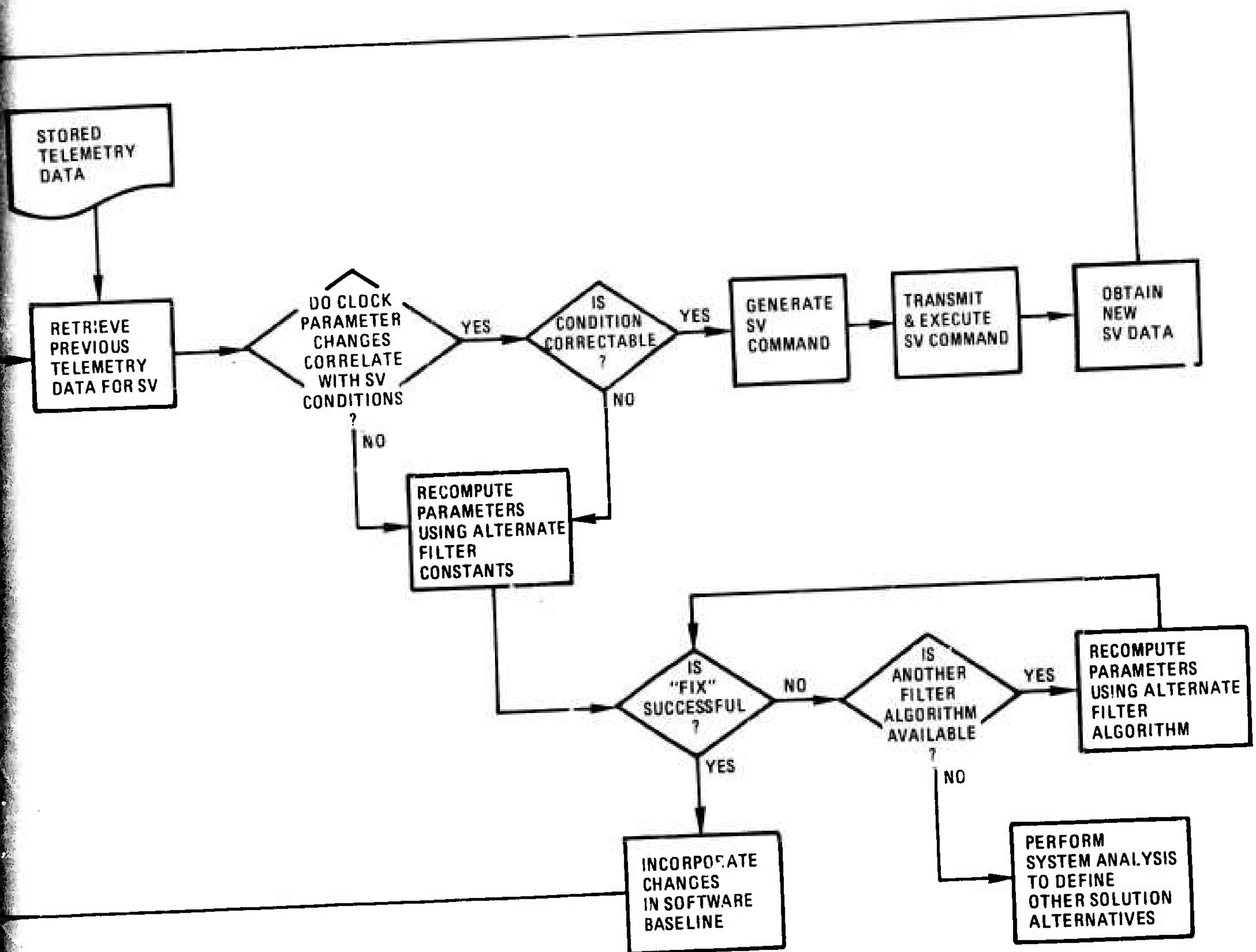


Figure 4-9 Decision/Action Diagram for Typical Clock Anomalies (Phase I)

SECTION 5

CONTROL SEGMENT TESTING

Normal, routine, on-going operational testing in the GPS Control Segment provides alignment and calibration, continuing performance monitoring, routine maintenance and fault detection and isolation. Alignment and calibration assumes an especially important role in the monitor stations, which have the prime mission of determining satellite orbital and electrical performance.

The basic approach taken is to rely, to the maximum extent possible, on testing in the Control Segment performed under control of the local computing facility within each station. Computer control is essential for tests which involve spread-spectrum signals, because of the necessity to control code states, both in the test signal generator and in the receivers being tested. Human control imposes severe limitations on the test techniques and would require additional hardware to effect a workable man-machine interface.

Each of the Control Segment elements have peculiar mission requirements, and consequently equipment complements, which demand test equipment particularly adapted to the operation which is being supported. The tests required to calibrate and maintain the GPS Control Segment elements are summarized in Table 5-1 which shows that, except for the communications equipment tests, the tests are in fact unique to each class of station: 1) the monitor stations primarily measure satellite performance, and 2) the upload station primarily transmits data to the satellite's memory. The testing requirements reflect the unique mission of each type of station.

Once the requirements for alignment and calibration have been satisfied, periodic tests are performed to detect degradation of performance and to indicate the need for and type of tests required to identify the source of degradation and reinitiate the station where required. Usually, these continuing tests are performed by the same equipment which provided the initial alignment and calibration, but possibly with different parameters and procedures.

Fault detection occurs when the monitoring tests indicate that degradation has occurred, or that the station no longer performs within operational limits. Methods, procedures and equipment for fault detection are discussed in paragraph 5.3. Subsequent tests provide fault isolation to identify the lowest replaceable unit which has failed. Paragraphs 5.4 and 5.5 identify the software test and

TABLE 5-1
GPS TEST SUMMARY

PARAMETER/FUNCTION	MS	US	MCS	SCF
L1 Received Signal Strength	o			
L2 Received Signal Strength	o			
1.8 GHz Uplink Signal Strength, (SCF)				o
2.25 GHz Downlink Signal Strength				o
1.8 GHz Uplink ERP (US)		o		
US Antenna Collimation		o		
1.8 GHz Xmtr Output Power, Radio Silent		o		o
1.8 GHz Exciter Output Power		o		o
Baseband Level		o		o
Baseband AM		o		o
Baseband I. O. S. Frequencies		o		o
Uplink Carrier Frequency		o		o
L1 Carrier Frequency*	o			
L2 Carrier Frequency*	o			
Uplink Mod. Index		o		o
2.25 GHz Downlink Mod. Index				o
1.024 MHz Downlink S/C Frequency				o
User Receiver LO and VCO Frequencies:				
10 MHz	o			
15 MHz	o			
40 MHz	o			
4 (1 - 1/157.5)	o			
10 (1 - 1/157.5)	o			
L1 Local Oscillator	o			
L2 Local Oscillator	o			
15 MHz VCO	o			
Code State, C-Code	o			
Code State, P-Code	o			
Doppler, P-Code	o			
Satellite Oscillator Frequency	o			
Communications				
BER	o	o	o	
Group Delay	o	o	o	
Impulse Noise	o	o	o	
Sending Level, Line Side	o	o	o	
Receiving Level, Line Side	o	o	o	
Sending Level, Modem Input	o	o	o	
Receiving Level, Modem Output	o	o	o	

*Includes Doppler

maintenance requirements to support the required tests and the testing required to monitor the performance of the software.

5.1 ALIGNMENT AND CALIBRATION

5.1.1 Scope

Alignment and calibration (A & C) is the process which assures that the station shall perform its mission within established tolerance limits, and maintain performance within specified limits, as distinguished from routine maintenance or fault location functions.

5.1.2 Monitor Station A & C

The monitor station provides the means for collecting satellite tracking information needed for the determination of orbit parameters for each GPS satellite. To accomplish its mission, each monitor station (refer to Figure 5-1) must provide capabilities to:

a. Receive the C/A-code modulated signal on the L1 frequency.

b. Receive the P-code modulated signal on the L1 and L2 frequency.

c. Measure pseudo range to each satellite

d. Determine time differences between arrival of L1 and L2 signals.

e. Demodulate data from the C/A and P signals

f. Aid acquisition by computing carrier Doppler and PN code state

g. Sequence satellite monitoring activities

h. Collect local meteorological data

i. Control communications with the MCS

j. Automatically monitor and test the hardware to verify its performance.

A & C is accomplished by use of a satellite-group simulator. This equipment generates four simulated satellite signals on L1 and on L2. The PN code states and data message information are pre-programmed in a P-ROM so that the monitor station will derive pseudo-range, acquisition data, and doppler offsets. The data is stationary and the PN codes do not progress to simulate satellite motion. The L2 signals are routed through a 0.1 microsecond delay line to simulate

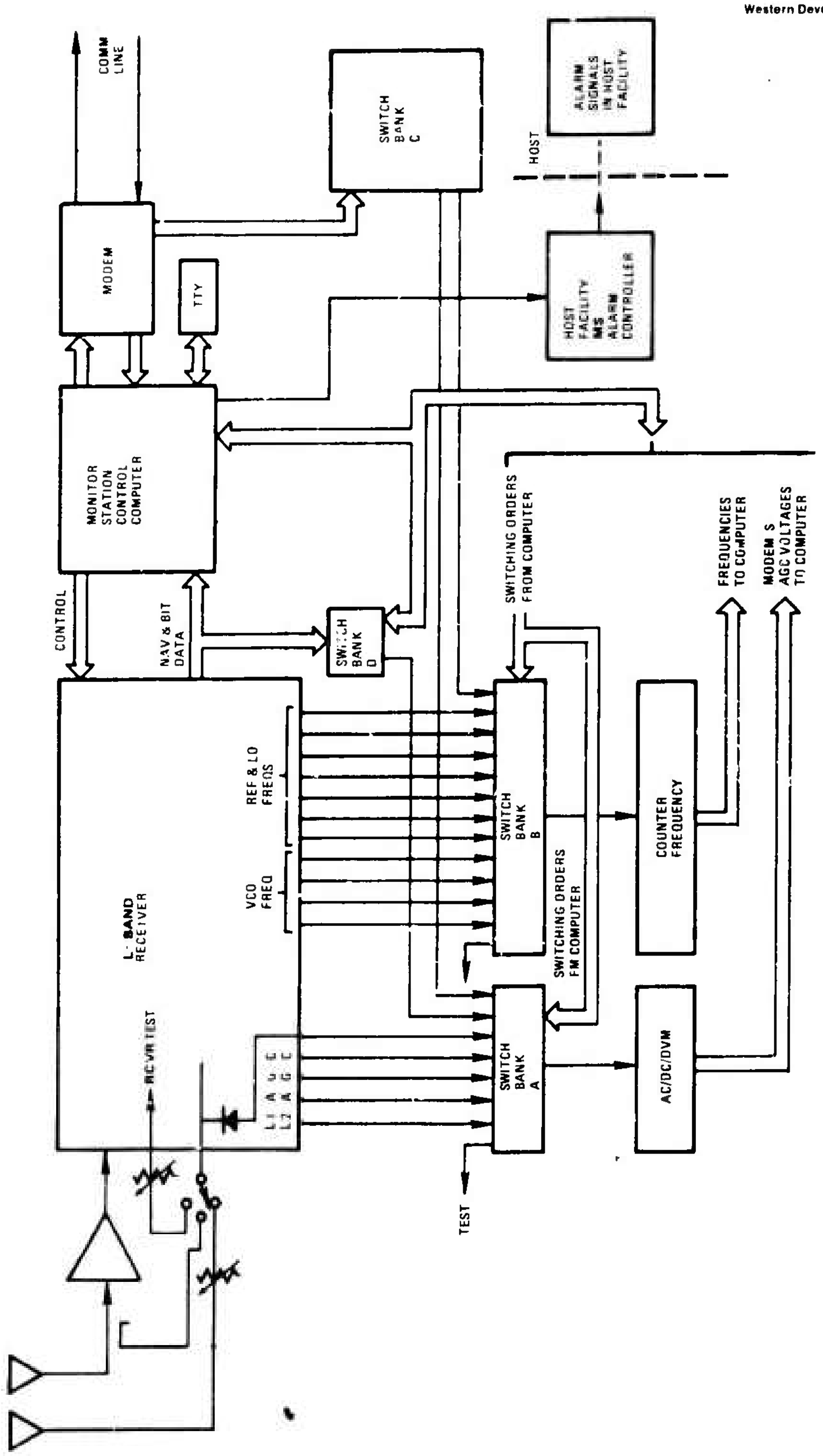


Figure 5-1 GPS Monitor Station Test Plan

ionospheric path distortion. The monitor station functions listed from "a" through "e" above are verified by use of this satellite simulator, and the navigational capabilities are evaluated by comparing the surveyed geographical position programmed into the simulator with the position output of the monitor station.

The A & C tests examine the antenna, radio receiver and the modems. The digital equipment is self-checking through use of software supplied by the computer vendor(s). Initial A & C tests are:

Antenna gain/pattern

Test loop insertion loss

Line loss, antenna to preamplifier

System noise power density

AGC voltages vs signal inputs

Local oscillator and reference frequency measurements

Code state acquisition

Secondary standard frequency

Modem voltage levels

Modem sending frequencies

The antenna gain and pattern are measured by the antenna vendor and verified after the antenna is installed in its permanent location in the monitor station. At this time the insertion loss from the test signal radiator to the receiving antenna are measured, and the test signal level set for routine performance and fault tests.

The AGC voltage generated in each of the digital to analog receiver channels is measured and stored for the test input level in routine use. These data will be re-examined periodically under computer control of the routine tests, and the results compared critically with the initial levels. The data interface levels from the user receiver to the station computer are examined initially to verify that they are normal, and this initial data will also be stored for later use as a standard for evaluation of routine test results.

In the same manner, the modem input and output signal levels will be measured and recorded for use during later routine tests. In addition to the amplitudes, the frequencies at the input and output on the line side of the modem will be measured. The modems have automatic backup capability and self-test features. When these functions are activated they are noted by the computer and set the local alarm. The baseline tests performed by the built-in test equipment are all under computer control, but certain tests, such as the test loop insertion loss measurement, will be performed manually using portable test equipment.

5.1.3 Upload Station A & C

The upload station is an S-band transmitter, antenna, computing facility and air check receiving equipment, along with built-in test equipment. The US is collocated with one monitor station, which provides the downlink needed to verify receipt of the data load in the satellite

The antenna in the US is for transmitting only, and thus it must be programmed by the computer to follow the predicted orbit of the satellite. Since no autotracking capability is available, the antenna collimation becomes a matter of great importance to the successful operation of the US.

Initial collimation, and the routine tests which follow it, require a boresight facility. For the GPS there is no need for fly-by calibration, and therefore no optical target or telescope is supplied. Collimation of the r-f beam with the shaft angle encoders is accomplished by illuminating the boresight antenna with the transmitting antenna, and measuring the intercepted r-f power. The measurement is sent to the US computer, where it is stored along with the shaft angle encoder outputs. The location of the boresight tower is surveyed and known to within one minute of arc, with the result that the accuracy of collimation is easily determined by evaluating the computer printout of intercepted power variation with shaft angle changes.

The boresight range must provide a long enough path to make the approaching wave front effectively planar at the point of reception, the "far field" region. The far field is considered to be the region beyond the distance

$$d = 2D^2/\lambda$$

where

D = antenna diameter

λ = wavelength

The far field lies beyond the 800 foot point for a 15 foot antenna working at 1.8 GHz.

Reflections from the earth between the sending antenna and the receiving antenna are a source of boresight error which must be considered. For example, a reflection arriving with -20 dB power compared to the main beam power, will induce an error of 0.2 of half the 3 dB beam width. Thus, it is important to raise the boresight

antenna above the reflected image of the first and second sidelobes whenever feasible. For 1800 MHz, a 15-foot transmitting antenna 30 feet above ground level, a satisfactory boresight range design is shown in Figure 5-2.

Gain of the boresight antenna should not be too low. Therefore, a circularly polarized, 20 dB gain horn will be used, located 100 feet above the surrounding terrain.

The boresight instrumentation is a sensitive power meter, located in a weatherproof enclosure at the foot of the boresight tower, connected to the horn by 100 feet of RG-214 coaxial cable. The power meter provides dBm outputs in logic level, BCD. The BCD is converted to binary and transmitted in serial, asynchronous format back to the site computer via a communications circuit.

The general plan for US testing is shown in Figure 5-3. Within the US, the site computer programs the voltage inputs to a digital voltmeter and a frequency counter. The measured radio frequency voltages are represented by the dc output of a crystal rectifier. The digital voltmeter has autoranging, and provides its outputs in digital format for application to the computer input buffer. The voltage functions measured are:

Aircheck receiver input

Aircheck receiver video output

Exciter power

Exciter modulating input signal

Baseband assembly input logic levels

Baseband assembly output video level

Uplink detector logic levels

Uplink detector inputs

Uplink detector AM percentage

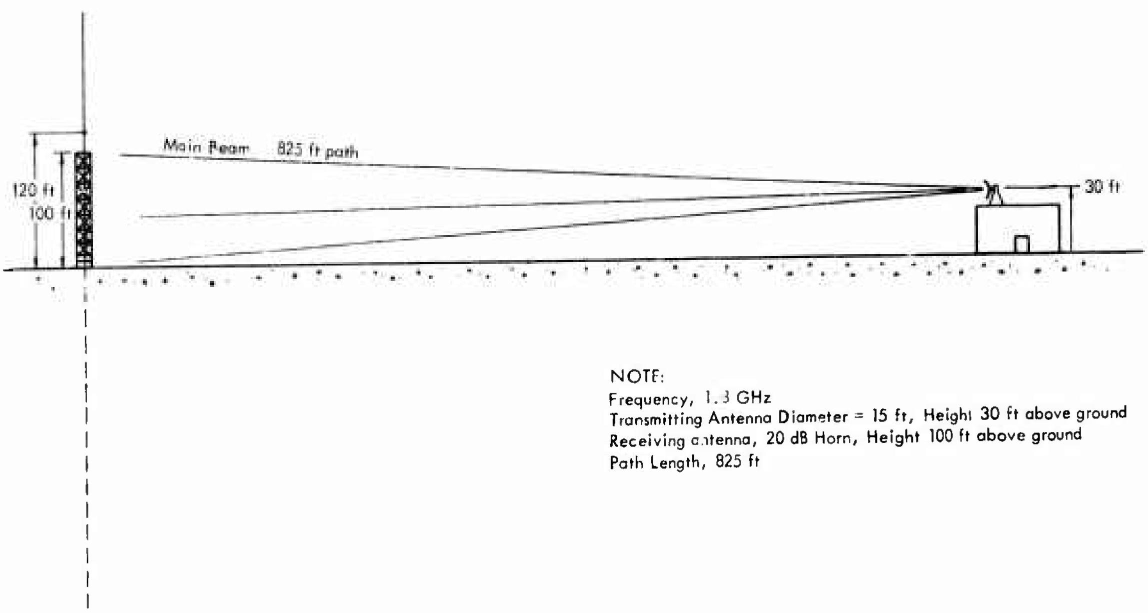
Modem inputs

Modem outputs

Frequencies are measured by an autoranging counter having digital logic level outputs, which are applied to the computer input buffer. Frequencies measured are:

Transmitted carrier frequency

FSK baseband 1, 0, S, frequencies



NOTE:
Frequency, 1.3 GHz
Transmitting Antenna Diameter = 15 ft, Height 30 ft above ground
Receiving antenna, 20 dB Horn, Height 100 ft above ground
Path Length, 825 ft

Figure 5-2 Farfield Boresight Tower

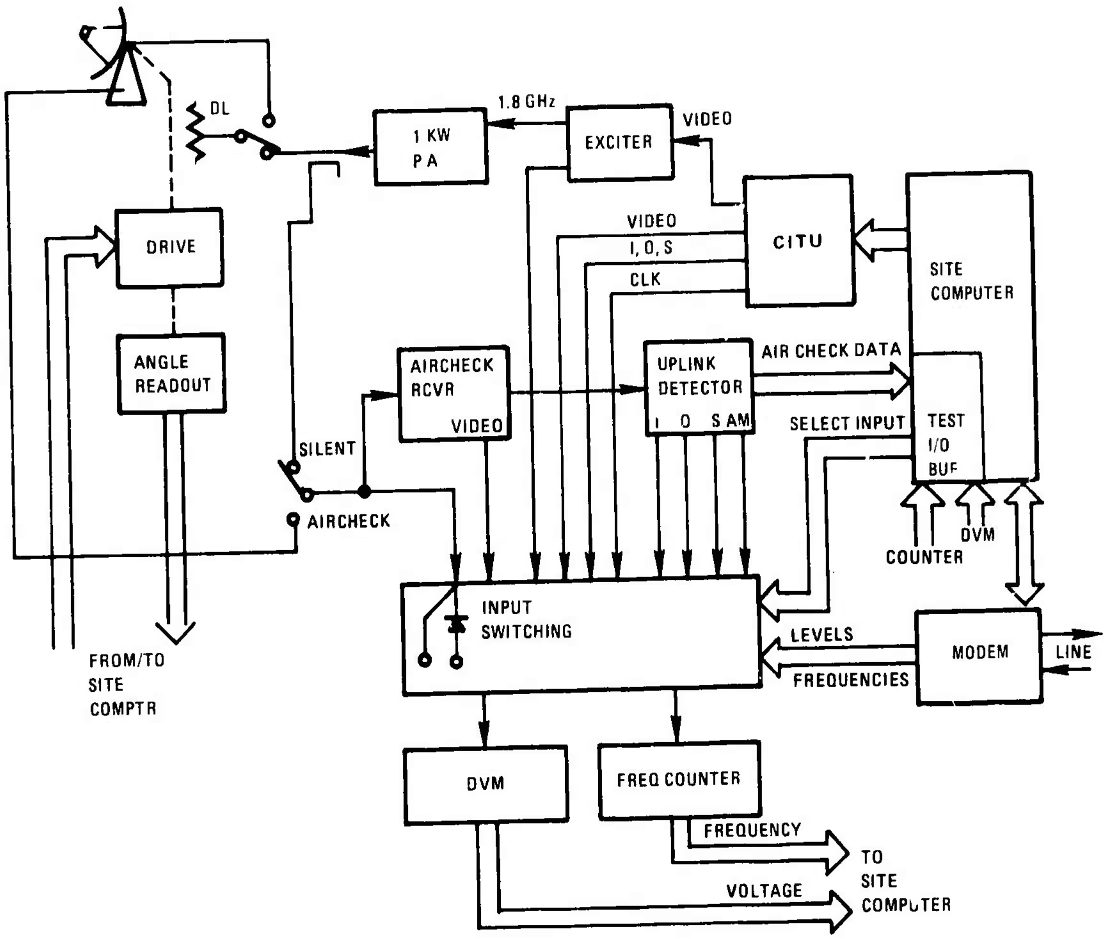


Figure 5-3 Upload Station Test Plan

Modem line frequencies

The modems have internal self-check features, and automatic backup in case of line trouble. These functions report to the computer when they are invoked.

5.1.4 Master Control Station, A & C

The A & C activities at the MCS are provided by the software and manual control. The modems in the MCS are automatic, and in the event of line trouble they can dial up backup lines to maintain the circuit. They have self testing capability; in the event of malfunctions the computer is notified of trouble and in turn advises the operators of trouble.

5.1.5 SCF A & C

The SCF attends to the housekeeping activities of the satellites, using standard SGLS equipment and techniques. Alignment and calibration is provided by the SCF for its own equipment. The requirements for the A & C are provided by the space vehicle designers, to assure mutual compatibility. The SCF has no direct responsibility other than to maintain the satellite. However, there is the possibility that one or more of the SCF stations may be used in a backup role due, for example, to desensitization of a space vehicle receiver and the consequent need for extremely strong uplink signals. Therefore, the ability of SCF computers to receive, format, and forward the data load on the uplink must be demonstrated as an A & C task.

5.2 OPERATIONAL PERFORMANCE MONITORING

During normal operation there are tests which will be performed without interfering with normal operations. Tests of this type are those which continuously monitor the performance of the monitor and upload station equipment. Anomolous performance is detected and where test results indicate normal performance, the results of the tests are retained in the computer memory long enough to establish trends useful for, 1) prediction of maintenance requirements and, 2) reliability analyses.

5.2.1 Monitor Station Operational Maintenance

Operational maintenance tests in the unmanned monitor stations are performed automatically by computer controlled switching and test equipment. In addition to the test capabilities provided in the station design as built-in test equipment (B.I.T.E.), the receivers in the monitor stations are equipped with built-in tests to locate any defective module in the receiver. This receiver B.I.T. interfaces

with the reports to the site computer. Thus, the receiver B.I.T., in conjunction with the monitor station B.I.T.E., enables the MCS to call up any test function desired, or to initiate a pre-programmed test routine which provides continuing evaluation of the monitor station's condition. The receiver provides go/no-go status bits, and in addition, the MS B.I.T.E. measures the AGC voltages from each receiver and the frequencies of the four VCO's and three internal references. The modem input and output voltages are monitored by the DVM, and departures from a normal tolerance are reported to the MCS, or, in the event that the modems are inoperative, the failure activates a local alarm to summon maintenance personnel from the host facility.

5.2.2 Upload Station Operational Maintenance

The upload station is manned at minimum levels, which makes the high degree of automation used in the monitor stations unnecessary, and the maintenance tests therefore combine automatic tests and manual tests in an optimal manner.

Under computer control, the performance of the antenna and slave bus is evaluated by automatically boresighting the antenna.

This test also provides a check on the EIRP seen by the boresight system. Analysis of the printed test data over periods of days and weeks provides trend information for maintenance planning.

The uplink transmitter is a 1 kW amplifier driven by an exciter delivering 2 watts of power. Both of these units have signal sample outputs, from which the power and carrier frequency are monitored.

Baseband signals to modulate the exciter are generated in a baseband assembly unit. Periodic monitoring of the data input levels, video output level, amplitude modulation factor, and the 1-, 0-, and S- tone frequencies are accomplished under control of the computer.

The amplitude modulation factor is measured as a by-product of the uplink monitoring process, which recovers the uplink carrier to obtain the timing wave from the AM, and uses the derived clock pulses for bit decision timing. The amplitude and occurence of the 1, 0, and S signals are measured by the DVM under control of the computer.

The modems in the upload station are monitored and evaluated in the same way as those in the monitor stations, except that in the event of trouble or failure the alarm is activated locally rather than in the host facility.

5.3 APPLICATION OF BUILT-IN TEST EQUIPMENT

Testing in the Control Segment will be performed primarily with built-in test equipment. Tests requiring additional instrumentation will always be performed by maintenance personnel using either portable instruments in the GPS inventory or from nearby installations. This section is concerned primarily with the built-in test equipment, but lists the portable test and maintenance equipment.

5.3.1 Monitor Station Test Equipment

The built-in test equipment consists of two instruments and their input and output devices. These are a digital voltmeter and a frequency counter.

5.3.1.1 Digital Voltmeter. The MS is unattended in normal operation, and the voltmeter selected must therefore be remotely controllable and provide automatic ranging. The remote control capability is used to select ac or dc volts, and the selection is made by the processor at the time the processor selects a given test point. Once the ac or dc decision has been made, the voltmeter provides a BCD output in parallel format with DTL-TTL logic levels. The requirements for the voltmeter are:

dc volts	10 mV to 100 V
ac volts	100 mV to 100 V
Frequency range	25 Hz to 100 MHz
Input Impedance	
dc 10 MHz	10M, 19 pf
10 MHz - 10 MHz	50
Output data	3 digits, 1, 2, 4, 8 BCD
Output Levels	0 - 5V nominal
Remote Control	ac or dc select
	Strobe (read pulse)
	115 ±10% V, rms, 60 Hz

5.3.1.2 Frequency Measurement. Frequency measurements are performed by an autoranging digital counter. As in the case of the digital voltmeter, input signals are selected by a multi-pole switch under control of the computer, and the counter is also remotely programmable. Outputs from the counter are BCD, 1 - 2 - 4 - 8 format with TTL levels. The requirements for the counter are at least the following:

Frequency range	20 Hz to 50 MHz
Sensitivity (hi-Z)	0.1V rms, minimum
Input Impedance	1 M, shunted by 25 pf
Sensitivity (50)	5 mV rms, minimum

Output format	BCD, 1 - 2 - 4 - 8, 7 digits
Output levels	DTL-TTL
Remote Control	All functions except sample rate
Power	115 ±10% V rms, 60 Hz

5.3.1.3 Instrument Input Selection. - Inputs to the voltmeter and the frequency counter are selected by a switching device, which can route every input to the BITE from the MON equipment under test to either the voltmeter or the frequency counter. The switch points are compatible with 50 ohm r-f circuits.

Test signals generated by the B.I.T. in the receiver must be transferred to the input of the system or to the input of the receiver to provide the antenna-preamp fault isolation capability. This function is performed by a coaxial switch having a minimum of 60 dB isolation between the energized output port and the de-energized output port. Each output port has an r-f attenuator in its line, so the signals injected will have a net gain difference equal to the preamp gain summed with the line losses.

5.3.1.4 Test Antenna. Test signals are injected into the MON antenna from a linearly polarized radiator located at a distance of at least 3 meters from the MON antenna.

5.4 SOFTWARE TEST AND MAINTENANCE FUNCTIONS

The Real Time test and maintenance software function shall be capable of the following:

a. Control of the testing of the master station and mointor station hardware

b. Control of the Signal Strength calibration and measurement task at the monitor station using the signal strength calibrator.

c. Storage of the results of the above testing and calibration in a data base for subsequent retrieval by the master station processor.

5.4.1 Real Time Test/Inputs

Information necessary to perform the real time testing shall be obtained from the operator commands and from the individual chassis test points.

5.4.1.1 Operator Commands. The Real Time Test function can be initiated from either station. The operator commands to control testing will turn on the built-in test equipment (BITE), take the monitor station equipment off line, connect the BITE to the monitor station equipment, generate or initiate test signals from specific sections of the BITE to specific monitor station chassis, and initiate other testing functions as required. The operator commands to control signal strength calibration will turn on the signal strength calibrator, take the monitor station equipment off line, connect the generator to the monitor equipment, and initiate hte calibration sequence.

5.4.1.2 Hardware Test Point Data. Monitor station test data shall be obtained from each of the six types of chassis-level equipments which are:

Antenna/preamp package
User receiver, complete
IF/digital processor, part of user receiver, (four separate units)
User processor
Station processor
Communications modem

5.4.2 Real Time Test/Processing

Processing of the test and maintenance function shall consist of interconnecting the BITE and monitor station equipment, generating test signals, interpreting the data from each test point, and formatting the results for display.

Processing of the signal strength calibration function shall consist of interconnecting the signal strength calibrator and the monitor station equipment, controlling the stepping of the signal strength calibrator, measuring and converting the AGC to received power, and then adjusting the received power figures to calculate the desired final result of transmitted power.

5.4.2.1 Control Testing Using BITE

a. Process Operator Commands

1. Provide Validation. Each operator command received is checked to see if it is in the list of valid commands, and if the parameters are within the acceptable ranges.

Invalid commands are rejected and the operator is required to re-enter his request.

2. Substitute Defaults. Where the operator has entered a recognized, shortened form of a multi-component command, and software will supply the omitted parts so all required functions are performed.

3. Interpret Commands. Each command received is broken into its component parts and the appropriate operation codes are sent to the hardware components affected, the requested software modules are addressed, or other appropriate action is taken.

b. Control Switching of BITE/Equipment. The monitor station hardware to be tested or calibrated is commanded to go off-line, or out of the real time mode, where necessary, and the BITE components required for the particular test requested are activated and connected to the monitor station equipment components.

c. Monitor Equipment State. The state of equipment, chassis, or hardware modules, which can be determined by hardware sensors, is monitored after it has been commanded to change state by the processor.

d. Generate Test Signals. Signals or data required to be input to test the monitor station equipment components are generated by the processor, or initiated by the processor, or initiated by commands to the test equipment, as appropriate.

e. Monitor Received Signal or Test Results. Signals generated by monitor station equipment being tested, or other pertinent output test results are examined by the processor software and go/no-go or in-range/out-of-range conditions are determined.

f. Interpret Test Point Data and Format Results. Test results are examined and the next test to be run in determined, possibly in conjunction with the test operator. Raw input data is converted to readable text and formatted for display, storage, or transmission.

5.4.3 Real Time Test/Outputs

Outputs shall consist of test signals, control parameters, console displays, test results, updated operations log, and a notification of improper equipment response.

5.4.3.1 Send Test Signals or Updated Control Parameters. Various test signals appropriate to the test equipment, module under test, type of

test, and phase of testing shall be generated by the processor or initiated in the test equipment and output. Parameters controlling the progress or sequence of the testing shall be updated as necessary and output to the BITE or modules under test, as required.

5.4.3.2 Provide Console Displays. Console displays shall be formatted and output made available, showing test progress, test results, calibration results, measurement results, operator communications, and any other appropriate material.

5.4.3.3 Update Operations Log and Store Test Results. The Operations Log shall be maintained with a history of testing, measurements performed and the significant results stored. Test results shall also be stored in a data base for subsequent retrieval and use by other sections of the software.

5.4.3.4 Send Alarm if Improper Equipment Response. Monitor and master station equipment and BITE having state sensors shall be monitored and an alarm shall be output if any equipment responds improperly to a command issued by the processor to change its current operating state.

5.5 SOFTWARE MAINTENANCE

Under executive control, self-checks will be performed on the computer/software by memory summing, instruction test, etc., to verify memory, arithmetic, and software module operation. It shall verify input/output by transfer of test problems and comparison of results.

SECTION 6

PERFORMANCE

Section 2 of this analysis report sets forth requirements, abridged from the System specification for the Control Segment (S237271), which are to be satisfied by the baseline hardware and software configurations described in Section 3 when these configurations are operated and aligned/maintained as described in Sections 4 and 5. This section examines various aspects of the performance of the aforementioned configurations in order to determine the extent to which the baseline control segment developed in this report satisfies the requirements levied upon it.

As an example of the performance evaluations addressed in this section, paragraph 6.2 provides an analysis of the RF uplink from the upload station to the GPS space vehicles. The uplink power budget developed in 6.2 is based upon a 15-foot diameter S-band antenna driven by a one kilowatt power amplifier -- the combination delivering an EIRP of 92.9 dBm. The analysis shows that his EIRP does support the required uplink error rate of 10^{-5} if a 1.0 radian modulation index is used. Hence, the analysis confirms that the baseline configuration satisfies its upload requirements. However, the analysis also reveals the conditions under which the requirements are met, ie, using a modulation index of 1.0 radian. In a similar fashion other analyses in this section address the performance of the data processing equipments, the availability of the control segment, etc. for the purpose of showing compliant (to the segment specification) operation of the CS configuration baseline. Three major categories of segment performance are treated:

a. The ability of the CS to meet the error budget allocations

b. The ability of the CS equipment to meet the processing and communications requirements implicit in the segment design

c. The ability of the CS to meet the allocated availability requirements

6.1 SEGMENT ERROR ANALYSIS

Probably the most important single analysis in the study is the Error Budget Analysis (Part II, Volume C, Report 8) which includes an evaluation of the ability of the Control Segment to meet its allocated part of the system error budget. Factors considered in this analysis include the following:

a. Signal strength at the MS antenna (L1 and L2)

b. MS antenna gain

c. MS receiver noise

d. MS clock stability

e. Ionospheric correction accuracy

f. Tropospheric correction accuracy

g. Contribution of smoothing to noise reduction

h. Tracking network timelines

i. Station location uncertainties

j. Geopotential uncertainties

k. Ephemeris and clock estimation algorithm errors

l. Ephemeris representation errors

This analysis shows that the Control Segment contributes less than 12 feet to the 1σ UERE when measurements are made 2 hours after satellite clock update.

6.2 SEGMENT COMMUNICATIONS ANALYSIS

The segment involves two distinct communications problems:

a. S-band TT&C communications between the Upload Station and Satellite Vehicle

b. Landline communications between the MCS and the monitor and upload stations, and the MCS and NWL and the AFSCF.

Analysis of the S-band communications from the upload station is contained in Table 6-1 . This analysis shows that an EIRP of 92.9 dBm will support the required uplink error rate of 10^{-5} if a 1.0 radian modulation index is used.

Analysis of the segment landline communications is contained in Telecommunications System Cost Analysis (Part II, Volume C, Report 3), and MCS/STC Communications Analysis (Part II, Volume C, Report 4). The first report shows that unconditioned dial up lines will meet the segment requirements. The second report shows that communications with the AFSCF STC is best accomplished using a dedicated minicomputer based tape terminal in the STC.

TABLE 6-1

UPLINK POWER BUDGET

The uplink is a SGLS-compatible, 1000-band ternary FSK digital data link operating with 1 radian direct modulation on the 1800-MHz carrier. Values apply to 5° elevation of incoming signal.

LINK ELEMENT	VALUE	UNITS
Transmitter Power, 1KW	60	dBm
VSWR Loss, 2.4:1 worst case	-0.8	dB
Line Loss	-0.9	dB
Rotary Joint Loss (2 ea.)	-0.2	dB
Radome Loss	-0.7	dB
Antenna Gain (Scientific Atlanta, 15 ft. dia.)	+35.5	dB
EIRP	92.9	dBm
Transmit Antenna Pointing Error	-0.1	dB
Path Loss (13,670 n.m.)	-185.6	dB
Polarization Loss (AR=2)	-0.3	dB
Atmospheric Loss	-0.4	dB
Receive Antenna Gain	0	dB
Receive Line Loss	-0.5	dB
Receiver Coupler	-4.5	dB
Power at Receiver Input	-98.5	dBm
Receiver Noise Density (NF=12 dB)	-162.3	dBm/Hz
Receiver C/No	-63.8	dB/Hz
Data Receiver Requirements		
Eb/No ($P_e = 10^{-6}$)	20.1	dB/Hz
Data Rate = BW = 1000 Bauds	30.0	dB-Hz
Modulation Loss (1 radian)	4.2	dB
Required C/No	54.3	dB/Hz
Achieved C/No	63.8	dB/Hz
Margin	+9.5	dB

6.3 CONTROL SEGMENT DATA PROCESSING CONFIGURATION PERFORMANCE ANALYSIS

This section will develop the performance characteristics required of the Master Control Station (MCS), Monitor Station (MS), and Upload Station (US) computer systems in order to support GPS control segment software functions. Particular attention is given to processor speeds and capabilities, main memory sizes, and auxiliary (disk) memory sizes.

6.3.1 MCS Computer System. The MCS computer system must support the software functions identified in Section 3 and repeated here:

a. Operations and control. This function performs the executive control and operator console support requirements for the MCS.

b. Monitor station control. This function provides for control of operations at each Monitor Station (MS).

c. Tracking data preprocessing. This function performs corrections of the raw tracking data for ionospheric and tropospheric retardation and for clock errors. It then smoothes the results for use in generation of ephemeris corrections.

d. Ephemeris correction estimation. This function computes corrections to the reference ephemerides to provide high accuracy data accuracy data to be uploaded in the navigation satellites.

e. Ephemeris prediction. This function applies corrections to reference ephemerides and fits polynomials to predicted ephemerides.

f. Clock state estimator. This function computes clock bias parameters for satellite, Monitor Station (MS) and Upload Station (US) clocks.

g. Clock state prediction. This function uses previous clock performance to model and predict future clock corrections.

h. Upload message generation. This function generates upload commands and data messages for uploading including ephemeris, clock and almanac data.

i. Upload Control. This function provides the support of operations personnel in commanding the US from the MCS and monitoring the status of the upload process.

j. Satellite memory image update. Based upon upload results, this function maintains an image of each satellite navigation subsystem memory.

k. System status monitoring and fault detection. This function monitors status indicators for all Control Segment equipment and assists in detection of faults.

l. Navigation performance evaluation. This function evaluates the navigational accuracy of data generated in the Control Segment from data received from the MSs and US.

m. System Scheduling function. This function generates the station operations and communication schedules for all Control Segment stations.

n. Acquisition almanac generation. This function translates satellite state vectors into orbital elements which are uploaded into the navigation satellites.

o. Communications. This function provides two-way communications between the MCS and the Mss, the US, the AFSCF, and the NWL.

6.3.1.1 MCS Processor Speed and Capabilities. A general purpose digital processing unit (CPU) with a conventional instruction repertoire provides basic support for MCS software. The CPU includes hardware index registers, load and store registers, and arithmetic registers. The basic instruction set includes load and store instructions, arithmetic (add, subtract, multiply, and divide) instructions, logical and shift instructions, data transfer (I/O) instructions, and test and jump instructions. The registers and instructions must allow 32 bit operands. The CPU must be capable of randomly addressing all of main memory for reading and writing.

For support of ephemeris estimation and prediction, and clock estimation and prediction functions, the MCS processor must provide at least 48 bits of precision in floating point arithmetic operations. This precision may be obtained by software support. If this is the case, execution times used for analyzing processor speed must include all software overhead necessary to achieve the specified precision.

For analysis and evaluation purposes, processor speed is expressed in thousands of instruction executions per second (KIPS). An "instruction" is an average instruction defined by the following mix:

Arithmetic - Floating point with 48 bits of precision	15.8%	
Add/Subtract		12.6%
Multiply		2.3
Divide		0.9

Logical	21.2%	
Compare		10.6%
Shift 6 Bits		7.1
And/Or		3.5
Control	54.8%	
Load/Store		30.0%
Conditional Branch		20.0
Increment and Store Index		3.1
Move Register to Register		1.7
I/O Control	8.2%	
Programmed I/O Transfer		2.2%
Initialize Buffered I/O		3.0
Interrupt Response		3.0
		100.0%

Table 6-2 illustrates the application of this mix to evaluation of three commercially available computers.

The analysis that follows develops an estimate of 110 KIPS for the peak load on the MCS processor. This analysis is summarized in table 6-3 . According to a study produced by the Air Force Systems Command, CCIP-85, the risk of incurring relatively high software costs is significantly reduced if the processor is sized for 50 percent utilization of its speed capacity. Accordingly, the estimated speed requirement of the MCS processor is approximately 220 KIPS. Thus 50 percent of the processors speed capacity is allocated to indirect operating system overhead (memory management, task scheduling, etc), idle CPU time (wait for I/O, etc), safety and growth.

TABLE 6-3
MCS PROCESSOR PEAK LOADING

Functions	Contribution to Peak Load KIPS
Continuous Background Functions	5.7 KIPS
Upload Sequence Functions	
Ephemeris Estimation	0.8
Clock Estimation	11.7
Ephemeris Point Prediction	73.9
Ephemeris Polynomial Fit	14.5
Clock Prediction	0.5
Upload Message Generation	2.9

TABLE 6-2

PROCESSOR EVALUATION EXAMPLE

MCS INSTRUCTION MIX		CDC CYBER 70/72		PDP 11/45		SEL 8500	
	% OF MIX	EXEC. TIME ~μSEC	CONTR. ~μSEC	EXEC. TIME ~μSEC	CONTR. ~μSEC	EXEC. TIME ~μSEC	CONTR. ~μSEC
ARITHMETIC (64-BIT FLOATING)							
ADD/SUBTRACT	12.6	1.45	0.183	14.20	1.789	5.95	0.750
MULTIPLY	2.3	6.05	0.139	18.65	0.429	16.15	0.371
DIVIDE	0.9	6.05	0.054	19.60	0.176	28.05	0.252
LOGICAL							
COMPARE	10.6	0.85	0.090	[illegible]	0.303	[illegible]	0.170
SHIFT (6 BIT)	7.1	0.95	0.067	2.83	0.201	2.55	0.181
AND/OR	3.5	0.85	0.030	3.73	0.131	1.60	0.056
CONTROL							
LOAD/STORE	30.0	1.25	0.375	1.88	0.564	1.60	0.480
CONDITIONAL BRANCH	20.0	1.65	0.330	1.13	0.226	1.60	0.320
INCR. & STORE INDEX	3.1	1.95	0.060	2.78	0.086	2.55	0.079
MOVE REGISTER	1.7	0.85	0.014	0.90	0.015	1.60	0.027
I/O CONTROL							
PROG. I/O TRANSFER	2.2	0	0	1.88	0.041	5.10	0.112
INIT. BUFFERED I/O	3.0	0	0	5.64	0.169	4.25	0.128
INTERRUPT RESPONSE	3.0	7.50	0.225	9.70	0.291	6.60	0.198
AVERAGE INST. TIME			1.569		4.421		3.124
KIPS			637		226		320

Total Peak Load 110.0 KIPS

Peak loading of the MCS processor will occur during the upload preparation time period. To prepare an upload, ephemeris and clock state estimations must be produced, ephemeris and clock state predictions calculated and fit to polynomials, and finally, the messages formatted for each satellite. During this upload preparation period all non-essential functions are considered to be suspended for the peak loading analysis. This includes monitor station communications since the last batch of tracking data has been received prior to the start of upload preparation sequence.

Maximum time available for upload preparation is 30 minutes based upon the following:

a. All satellites loaded before start of test time (hour 0)

   1. 44 minutes (0.767 hours) are required for data transmission to US and for uploading four satellites

   2. Therefore, upload preparation must be complete by hour 23.233

b. At least 15 minutes of tracking data is required from all satellites prior to upload preparation

   1. Satellite No. 3 is the last to come into view and is seen from Elmendorf first at hour 22.283

   2. 3 minutes are required for acquisition; 15 minutes of tracking data are available for transmission to the MCS, 18 minutes after satellite No. 3 rises, or at hour 22.583.

   3. 3.25 satellite hours of tracking data are transmitted to the MCS at this time. Assuming a 500 b/s thruput on the transmission, this requires 0.073 hours (240 samples per satellite hour; 168 bits per sample)

   4. Therefore, tracking data is available for upload preparation at hour 22.656.

c. Thus, 0.577 hours (or about 35 minutes) are available between receipt of tracking data and transmission of upload data. Allowing 5 minutes for analyst initiation of the various operations involve, yields 30 minutes available at the MCS for upload preparation.

The MCS processor loading for each upload preparation function is distributed over 30 minutes, and the resulting loads summed to obtain peak loading. This is equivalent to assuming sequential execution of

all functions with no idle CPU time. Idle CPU time is minimized with a multiprogramming operating system and is accounted for later in a higher level analysis.

The upload is assumed to be prepared for four satellites. Peak loading for Phases 2 and 3 depends upon the number of satellites uploaded simultaneously and the upload preparation time constraint.

Estimates of each upload preparation functions contribution to peak load and the basis for each estimate is given below. All estimates are biased by 10 percent to allow for direct operating system overhead; ie, for services, such as I/O, provided by the operating system, initiated explicitly by the software functions.

Existing orbit and clock determination programs, Mustang and Mustang II, have been used to evaluate orbit determination techniques. Execution times for these programs on a Honeywell 6040 are used in this analysis to develop realistic estimates of instruction executions required to perform these functions.

a. Tracking Data Preprocessing (11.7 KIPS)

   1. 1 hour of tracking data required to be preprocessed at the start of upload preparation.

   2. 1 hour of tracking produces a maximum of 16 satellite hours of tracking data (4 monitors, 4 satellites).

   3. 5000 instructions required per tracking data sample

   4. 240 samples per satellite hour (sampling once every 15 seconds).

b. Ephemeris Correction Estimator (0.8 KIPS)

   1. A prototype Mustang program required 70 milliseconds to process each observation on a Honeywell 6040.

   2. Honeywell 6040 executes at approximately 300 KIPS

   3. 64 points must be processed at the start of upload preparation. This is one point every 15 minutes for 16 satellite hours of tracking.

c. Clock State Estimator (11.7 KIPS)

   1. Based upon executions of a prototype Mustang II program on a Honeywell 6040, clock estimation should not take longer than 8 seconds per clock.

   2. Honeywell 6040 executes at approximately 300 KIPS

3. four satellite clocks and four ground clocks are estimated

d. Ephemeris Point Prediction (73.9 KIPS)

1. A prototype Mustang program requires 56 milliseconds for each ephemeris point predicted on a Honeywell 6040.

2. Honeywell 6040 executes at approximately 300 KIPS

3. One ephemeris point is required for each four minutes of predicted orbit (this is required by the least squares polynomial fit analyzed below).

4. Five days of orbit predictions are required for four satellites.

e. Ephemeris Polynomial Fit (14.5 KIPS)

1. A sixth degree polynomial is used to represent each of three coordinates.

2. Twenty points, at four minute intervals, are required to perform at least squares fit which is sufficiently accurate over an 80 minute interval.

3. A detailed analysis of a FORTRAN least squares polynomial fit program, used for analysis of ephemeris representation techniques, indicates that approximately 16,500 instructions are required per polynomial produced.

4. 1,440 polynomials must be generated; one for each hour of the five day prediction period, for each of the three coordinates for four satellites.

f. Clock State Predictor (0.5 KIPS)

1. Not more than 200,000 instructions will be required per clock prediction.

2. Predictions are produced for four satellite clocks.

g. Upload Message Generator (2.9 KIPS)

1. Not more than 1,200,000 instructions will be required per upload message generated.

2. One upload message must be generated for each of four satellites.

h. Continuous Background Support Functions (5.7 KIPS)

1. Operations and control function will not require more than 60,000 instruction executions per minute average.

2. System status and fault detection will not require more than 120,000 instruction executions per minute average.

3. Navigation performance evaluation will be required to produce about four navigation solutions per hour average. A navigation solution will not require more than 500,000 instruction executions.

6.3.1.2 MCS Processor Memory. For general support of MCS software, random access parity memory, addressable in words of 32 or less bits, is required. Memory access time should be on the order of 1 usec, based upon the timing studies presented in section 6.3.1.1. However, the access time must be as required to support minimum processor speeds based on the instruction mix given in Section 6.3.1.1. This mix assumes 30 percent of the instructions executed are for direct memory access.

Estimates of memory size requirements for the MCS software functions are given in Table 6-4 . These estimates are based upon 32 bit words, however, the equivalent number of 16 bit words is considered acceptable. Processor memory requirements are summarized in Table 6-5 .

TABLE 6-4

MCS SOFTWARE SIZING ESTIMATES

Operations and Control	6.0 K*
Communications Control	2.0 K
Tracking Data Acquisition and Preprocessing	2.0 K
Ephemeris Correction Estimator	5.0 K
Ephemeris Prediction	8.0 K
Clock State Estimator	4.0 K
Clock State Predictor	2.0 K
Upload Message Generator	4.0 K
Satellite Memory Image Update	0.5 K
Real Time Test and Maintenance Support	9.0 K
System Status Evaluator and Fault Detection	2.0 K
Navigation Performance Evaluation	6.0 K
System Scheduling	4.0 K
Acquisition Almanac Generation	4.0 K

*K = 1024 words of 32 bit memory

TABLE 6-5
MCS PROCESSOR MEMORY REQUIREMENTS

Operating System	16 K*
Operations and Control Software	6 K
Communications Software	2 K
Program Execution Area	32 K
• Managed by Operating System	
• Four Programs Loaded Concurrently	
Background Test Applications	8 K
• Includes Queuing Safety Factor and Growth Requirements	----
TOTAL	64 K

*K = 1024 words of 32 bit memory

The most critical period of MCS operation is during upload message preparation. In order to obtain the desired thruput without using a significantly more powerful processor, upload sequence functions must be executed concurrently for each satellite. Since the size of the largest function is estimated to be 8K of 32 bit words, 32K is allocated to multiprogrammed execution area to allow for four concurrent executions. An example of a memory structure possible during upload preparation is given in Table 6-6 .

TABLE 6-6

PROGRAM EXECUTION MEMORY AREA

Basis of 32K Estimate

- Execution area managed by multi-programming operation system
- Upload preparation for 4 satellites accomplished with at least 4 programs resident simultaneously

• Estimated size of largest program	8K
• Program execution area required	32K

Example of a possible upload preparation situation

• Ephemeris prediction for satellite 1	8K
• Ephemeris prediction for satellite 2	8K
• Upload message generator for satellite 3	4K
• Clock state predictor for satellite 4	2K
• Performance evaluation program	6K
TOTAL EXECUTION MEMORY AREA USED	28K
MEMORY AVAILABLE	4K

Operations and control function and communications function are expected to be resident in processor memory. Thus 6K and 2K, respectively, of available memory is allocated to these functions. A multi-programming operating system with the desired capabilities, typically requires about 16K of memory. Finally, 8K is allocated for background test support, growth and safety. This brings the total MCS processor memory requirement to the equivalent of 64K of 32 bit words.

6.3.1.3 MCS Disk Memory. Auxiliary random access mass storage (disk) is required at the MCS for storage of operating system tables and overlays, MCS functional software programs, and MCS data base, and for temporary file storage. Although this device is called a disk here, an random access mass storage meeting the requirements is satisfactory.

The necessary mass storage capacity is estimated at about 9 million 8 bit bytes, as indicated in Table 6-7 . According to a study produced

by the Air Force System Command, CCIP-85, the risk of incurring relatively high software costs is significantly reduced if memory is sized for 50 percent utilization of its capacity. Accordingly, the estimated MCS mass storage capacity requirement is 18 million 8 bit bytes.

Disk configuration and access speed requirements are those needed for efficient use by the operating system and for support of the GPS data base. Significant increases in operating system efficiency can generally be obtained by using more than one disk unit. However, this, and other disk configuration considerations, are dependent upon the vendor selected. For support of the MCS data base, the average disk access time requirement is estimated to be less than 50 milliseconds.

TABLE 6-7

MCS MASS STORAGE REQUIREMENTS

File Name/Content	Retention Period	Storage Required (100 bytes)
Control Segment Schedule File	7 days	4.0
MS/US Schedule File	7 days	1.0
System Operation Log File	2 days	10.0
MS/US Status File	2 days	1.0
MS/US Navigation Performance File	24 hr.	23.0
MS/US Meteorological Data File	24 hr.	7.7
MS/US Tracking Data File	30 days	4300.8
Processed Satellite Observation File	30 days	192.0
Ionospheric Observation Data File	30 days	19.2
Reference Ephemeris File	30 days	620.8
Satellite Estimated Epoch Corrections	7 days	63.2
Estimated Clock State File	7 days	44.4
Corrected Ephemeris File	7 days	118.3
Predicted Ephemeris File	2 days	103.7

Predicted Clock Coefficients File	2 days	19.2
System Calibration Data File	30 days	20.0
Satellite Memory Image File	2 days	200.0
Command and Navigation Message File	1 day	800.0
Satellite Upload Accept/Reject File	1 day	1.0
Satellite Status File	7 days	1.0
Satellite Telemetry File	7 days	10.0
Recurring Schedule Requirements File	N/A	10.0
Test Area Navigation Prediction File	1 day	3.0
Acquisition Almanac File	30 days	40.0
MCS Status File	7 days	1.0
Temporary Scratch File Space	N/A	1000.0
MCS Program Storage Space	N/A	500.0
Operating System Tables and Overlays	N/A	800.0
TOTAL MASS STORAGE ESTIMATE		8,914.3

6.3.2 MS Computer

The MS computer system must support the software functions identified in Section 3 and repeated below:

a. Operations and control. This function implements the station schedule and provides for control from the MCS or local operator terminal.

b. Data acquisition and preprocessing. This function assembles data from the status and navigation data bases for transmittal to the MCS.

c. Status monitoring and fault detection. This function monitors discrete equipment status indicators, controls the built-in test equipment and periodically checks processor and software status for detection of equipment and software faults.

d. Communications. This function receives data, control, and text messages from the MCS and transmits status, navigation data and text messages to the MCS.

e. Navigation initialization. This function provides initialization values for variables required to begin computing navigation solutions.

f. Navigation signal acquisition. This function generates commands which provide an aid to the L-Band receiver in acquiring satellite signals.

g. Navigation data assembly. This function assembles navigation data frames from satellites being tracked and checks frames for errors.

h. Navigation measurement processing. This function provides corrections to pseudorange and range rate for ionospheric and tropospheric retardation before these are used in the navigation solution.

i. Orbit propagation. This function provides extrapolation of satellite orbital elements.

j. Navigation computation. This function computes the station position and apparent velocity, and residuals from known station position.

6.3.2.1 MS Processor Speed and Capabilities. A general purpose digital processing unit (CPU) with a conventional instruction repertoire provides basic support for MS software. The CPU includes hardware index registers, load and store registers, and arithmetic registers. The basic instruction set includes load and store instructions, arithmetic (add, subtract, multiply, and divide) instructions, logical and shift instructions, data transfer (I/O) instructions, and test and jump instructions. The registers and instructions typically allow 16 and 32 bit operands. The CPU must be capable of randomly addressing all of main summary for reading and writing.

For support of navigation solution computations and tracking data preprocessing, the MS processor must provide at least 32 bits of precision on integer arithmetic operations and 24 bits of precision on floating point arithmetic operations. This precision may be obtained by software support. If this is the case, execution times used for analyizing processor speed must include all software overhead necessary to achieve the specified precision.

For evaluation purposes, processor speed is expressed in thousands of instruction executions per second (KIPS). An "instruction" is an average instruction defined by the following mix.

MONITOR STATION SOFTWARE INSTRUCTION MIX

ARITHMETIC - (FLOATING POINT WITH 24 BITS OF PRECISION)	15.8%	
ADD/SUBTRACT		12.6%
MULTIPLY		2.3
DIVIDE		0.9
LOGICAL	21.2%	
COMPARE		10.6%
SHIFT 6 BITS		7.1
AND/OR		3.5
CONTROL	58.8%	
LOAD/STORE		30.0%
CONDITIONAL BRANCH		20.0
INCREMENT AND STORE INDEX		3.1
MOVE REGISTER TO REGISTER		1.7
I/O CONTROL	8.2%	
PROGRAMMED I/O TRANSFER		2.2%
INITIALIZED BUFFERED I/O		3.0
INTERRUPT RESPONSE		3.0
		100%

The analysis that follows develops an estimate of about 24 KIPS for the peak load on the MS processor. This analysis is summarized in Table 6-8 . The risk of incurring relatively high software costs is significantly reduced if the processor is sized for 50 percent utilization of its speed capacity. Accordingly, the estimated speed requirement of the MS processor is approximately 48 KIPS.

TABLE 6-8

MS PROCESSOR PEAK LOADING ESTIMATES

MS Software Functions	Contribution to Peak Load KIPS
Operations and Control	1.444 KIPS
Data Acquisition and Preprocessing	0.862
Status Monitoring and Fault Detection	0.003
MCS Communications	9.000
Navigation Initialization	-
Navigation Signal Acquisition	-
Navigation Data Assembly	0.001
Navigation Measurement Processing	0.100
Orbit propagation	0.080
Navigation Computation	6.320
Total	17.800 KIPS
Operating System Overhead (30%)	5.340
Minimum Processor Capacity	23.140 KIPS

Peak loading of the MS processor occurs during normal tracking operations when four satellites are in view. In addition to support of tracking data sampling from the receivers, the processor must also accommodate communications and teletype load. The critical assumptions used to develop the estimates given in Table 6-8 are listed below.

a. Communication modem is driven at 2400 baud on a character at a time basis. Thirty instructions per character is assumed.

b. The teletype is driven at 110 bps on a character at a time basis. Thirty instruction per character is assumed.

c. The receiver will interrupt the processor 8 times per second. 120 instructions are executed to process each interrupt.

d. The real time navigation processing loop is executed once every 15 seconds.

e. Every 15 minutes, L^1 and L^2 pseudorange data (15 second intervals) is smoothed by a least squares polyniminal fit.

6.3.2.2 MS Processor Memory. For general support of MS software, random access parity memory, addressable in words of 16 or less bits, is required. Memory access time should be less than 10 usec, based upon the timing studies presented in section 6.3.2.1. However, the access time must be as required to support minimum

processor speeds based on the instruction mix given in section 6.3.2.1. This mix assumes 30 percent of the instructions executed are for direct memory access.

Estimates of memory size requirements for the MS software functions are given in Table 6-9 . Processor memory for operating system, MS software programs, and data buffers is estimated to be 18000 16 bit words. The risk of incurring relatively high software costs is significantly reduced if memory is sized for 50% utilization of its capacity. Accordingly, the estimated MS processor memory capacity requirement is 36,000 16 bit words or the equivalent.

TABLE 6-9

MS SOFTWARE SIZING ESTIMATES

MS Functions	Number of 16-bit Words Data & Buffers	Memory Resident	Not Memory Resident
Operating System	-	8000	4000
Overlay Load Area	-	2000	-
Operations and Control	896	710	-
Data Acq. & Processing	128	600	1000
Status and Fault Det.	-	100	3000
MCS Communications	128	100	-
Navigation Initialization	150	100	-
Navigation Signal Acquisition	300	350	-
Navigation Data Assembly	900	250	-
Navigation Measurement Proc.	138	200	-
Orbit Propogation	300	200	-
Navigation Computation	500	1950	-
Totals	3440	14560	8000

Total Processor Memory Required - 18000

Total Mass Storage for Software - 26000

6.3.2.3 MS Disk Memory. Auxiliary random access mass storage (disk) is required at the MS for storage of operating system tables and overlays, MS functional software programs, and for temporary storage of satellite tracking data. Although this device is called a disk here, any random access mass storage meeting the requirements is satisfactory.

The necessary mass storage capacity is estimated at 252 thousand 8-bit bytes, as indicated in Table 6-10. The risk of incurring relatively high software costs is significantly reduced if memory is sized for 50% utilization of its capacity. Accordingly, the estimated MS mass storage capacity requirement is 500 thousand 8-bit bytes.

TABLE 6-10

MS MASS STORAGE ESTIMATES

	Number of 8 bit bytes required
Operating System Tables	8000
Software Program Storage	52000
Tracking Data (24 hours)	192000
Total	252000

6.3.3 US Computer

In addition to supporting MS software functions given in section 6.3.2, the US computer must support the upload station functions defined in section 3 and repeated below:

a. Upload station antenna pointing. This function provides antenna positioning control and status for the command antenna.

b. Upload transmission. This function controls the transmission of command data to the space vehicle navigation payload.

c. Upload verification. This function monitors command verification telemetry words generated by the space vehicle navigation payload.

d. Upload Status reporting. This function generates command configuration and status messages for transmission to the MCS and US operator locations.

Since upload station software functions are performed on the same processor as, and concurrent with, MS functions, US requirements are developed as additions to MS requirements given in section 6.3.2.

6.3.3.1 US Processor Speed and Capabilities. Upload station software functions do not impose any additional capability requirements over those stated for the MS processor. In order to integrate both functions on the same computer, the US processor must be completely compatible with the MS processor.

However, minimum speed requirements of the MS processor must be increased to accomodate upload station functions. Table 6-11 gives

the estimated additional contributions to peak loading of each of the upload station functions. Adding these to the peak loading estimates for MS functions gives about 30 KIPS. In order to reduce the risk of increasing relatively high software costs, the processor is sized for 50 percent utilization of its capacity. Accordingly, the estimated speed requirement of the US processor is approximately 60 KIPS.

TABLE 6-11

UPLOAD STATION PROCESSOR LOADING

Functions	Phase Peak Load KIPS
UPLOAD TRANSMISSION	
FETCH (1/6 SEC)	.005
PARITY CHECK (1 SEC)	.120
FORMATTING	2.000
OUTPUT	.030
INTERRUPT PROCESSING	.030
RETRANSMISSION CONTROL	.050
VERIFICATION	
INPUT REQUEST (2/6 SEC)	.010
INTERRUPT PROCESSING (2/6 SEC)	.010
TEST A/R (1/6 SEC)	.002
SET DATA BASE ITEMS (1/6 SEC)	.002
ECHO CHECK (100/SEC)	3.030
STATUS REPORTING	
FORMAT CONFIG/STAT MESSAGE (1200/6 SEC)	.200
REQUEST OUTPUT (1/6 SEC)	.005
ANTENNA POINTING	
SLEW TO NEW VEHICLE (1/360 SEC)	.750
INTERPOLATION (1/SEC)	.120
SLAVE BUS I/O (10/SEC)	.200
TOTAL ADDITIONAL MONITOR STATION PEAK LOADING REQUIRED FOR UPLOAD PROCESSING	6.564

6.3.3.2 US Processor Memory. The required processor memory characteristics for the US processor are the same as for the MS processor.

Estimates of additional program and buffer storage requirements for each upload station function are given in Table 6-12 . Adding these to MS program and buffer storage requirements of 18000 16 bit words, developed in section 6.3.2.2, gives a total for the US of 20,184 16 bit words. In order to reduce the risk of incurring relatively high software costs, memory is sized for 50 percent utilization of capacity. Accordingly, the estimated US processor memory requirement is approximately 40,000 16 bit words or the equivalent.

TABLE 6-12

UPLOAD STATION PROCESSOR MEMORY REQUIREMENTS

PROCESSOR MEMORY	No. of 16-bit words PHASE I
TRANSMISSION FUNCTION	300
VERIFICATION	114
STATUS FUNCTION	210
ANTENNA POINTING	160
DATA BUFFERS	1400
TOTAL PROCESSOR MEMORY	2184

6.3.3.3 US Disk Memory. Upload software functions do not impose any additional requirements on the characteristics of the MS mass storage device.

Estimated additional mass storage capacity requirement for the US is 168 thousand 8-bit bytes. This includes 134 thousand for command upload data and 34 thousand for antenna pointing data. Adding this to MS requirements of 252 thousand bytes, gives a total of 420 thousand bytes for US mass storage. In order to reduce the risk of incurring relatively high software costs, mass storage is sized for 50% utilization of capacity. Accordingly, the estimated US mass storage capacity requirement is 840 thousand 8 bit bytes.

6.4 CONTROL SEGMENT AVAILABILITY ANALYSIS

This paragraph presents an availability analysis of the proposed Phase I Control Segment configuration. A preliminary Maintenance Concept is also described.

6.4.1 Requirements and Summary of Analysis Results

Paragraph 4.3 of Annex 2 to Attachment 1 to Contract F04701-73-C-0296 delineates availability requirements as follows:

> "4.3 Ground Equipment Availability Goal
>
> The Ground Equipment (ie, the Master Control Station and the Monitor Stations required for the operations of the Demonstration System) shall have, over any 10 day period, an operational availability goal of not less than 70% of the time based on 10 hour per day, 7 day per week utilization, etc. The maximum downtime shall be no more than 72 consecutive hours. The operational DNSS ground equipment shall have a total system availability goal of 99 percent, with ground system downtime not to exceed 2 hours. The maximum downtime of any operational monitor station shall not exceed 48 hours."

For Phase I availability requirements, Philco-Ford interpreted the availability requirement in a manner which is more stringent and which reflects the operational procedures and schedules described in Sections 3 and 4 of this report:

> "Based upon a 7 day per week, 24-hour per day operation, and being cognizant of the operational time-lines for Phase I, the Control Segment (formerly called Ground Equipment) shall provide no less than a 70% probability that satellites are properly uploaded, given the satellites are performing in accordance with their specifications."

An assessment of the proposed Phase I Control Segment configuration forecasts a probability of 86 percent that satellites will be properly uploaded.

For assessment purposes the analysis is partitioned into the four configuration item functional areas which comprise the Control Segment. The individual assessment results on the Configuration Item functional areas are tabulated below.

Config. Item Functional Areas	Forecasted Probability (%)
Monitor Station Function	97.34
Upload Station Function	99.02
Master Control Function	95.74
Telecommunications	93.8
Overall Control Segment Function	86.56

A detailed analysis of each function (except Telecommunications) is presented in Paragraphs 6.4.3 through 6.4.5. Telecommunications is to be provided by commercial land lines (AT&T) whose design and operational availability is outside the control of Philco-Ford. The Bell System Technical Reference (Publication 41005) relates experience

data showing a success probability of 93.8 percent and this value is used in the analysis for the telecommunications function.

6.4.2 Dimensions and Definitions

Following are definitions which are pertinent to the analysis.

6.4.2.1 Dimensions. A consistent set of dimensions is used throughout. All failure rates are in the dimensions of failures per million hours, MTBFs in hours, and MTTRs in hours. Availability and probability are dimensionless and expressed either as percent or in decimal format.

6.4.2.2 Availability and Probability of Success. If at some point in time a demand is placed upon a block of hardware, the probability the equipment is in an operable condition is its availability which is defined by the expression:

$$A = MTBF/MTBF + MTTR$$

The probability the equipment will remain in an operable condition (no failures) for a time period long enough to perform its intended function is given by the expression:

$$R = e^{\lambda T}$$

where:

λ = the equipment's failure rate

T = the time duration the equipment must function without failure

Thus, A is the probability the equipment will perform when powered up or a demand is levied upon it, and, R is the probability it will continue to perform without failure throughout the mission. Hence, the probability of accomplishing a specific function is:

$$P = A \bullet R$$

In the analyses which follow, the times, T, which the equipment must function without failure or other types of downtime, are determined by the operational time-lines delineated in Paragraph 4.2 of this document. The analysis takes the approach that if the monitor function is successful, the upload function is successful, the MCS computer function is successful, and the telecommunications function is successful, then the overall Control Segment's basic function of uploading satellites is successful. The probability of success is computed for each of the component functions and these component probabilities combined to give the Control Segment probability. The four component functions are performed at different times during the day as delineated by the operational time-lines. If a piece of

equipment is required for two or more functions, then it is included in the analysis two or more times.

6.4.2.3 Maintenance Time Computations. For a series string of equipment wherein all elements have to perform to realize success, the overall MTTR is computed by the expression:

$$\text{Overall MTTR} = \frac{\Sigma(\lambda_i)(MTTR_i)}{\Sigma \lambda_i}$$

where:

λ_i = the failure rate of the ith element

$MTTR_i$ = the MTTR of the ith element

In the case of redundant elements, system restore time is the time for an operator to recognize a fault has occurred and to switchover to the backup unit.

6.4.2.4 Redundancy. In the proposed configuration, all redundancies are mechanized such that a repairman may work on a faulted unit while the system continues to operate on the backup unit.

6.4.2.5 Offline Equipment. Offline equipment is equipment not vital to the overall task of uploading satellites. That is, the fact an offline item may be in an outage condition will not prevent execution of the basic uploading task. Offline equipment is not included in this analysis but is identified as those particular items occur in the analysis.

6.4.3 Analysis of the Monitor Station Function

The Control Segment incorporates four Monitor Stations. Monitor Station locations and their respective satellite in-view times per day (time-lines) are:

Vandenberg	13.92 hours
Alaska	15.00 hours
Hawaii	14.08 hours
CONUS	15.25 hours (worst case)

To accomplish successful satellite uploading, the Vandenberg station and any two out of the remaining three must perform their monitoring function. The Vandenberg station is both critical and unique because it is the "time reference" by virtue of the fact the System Time Standard works in conjunction with this station during satellite monitoring to establish system time. Figure 6-1 is a reliability

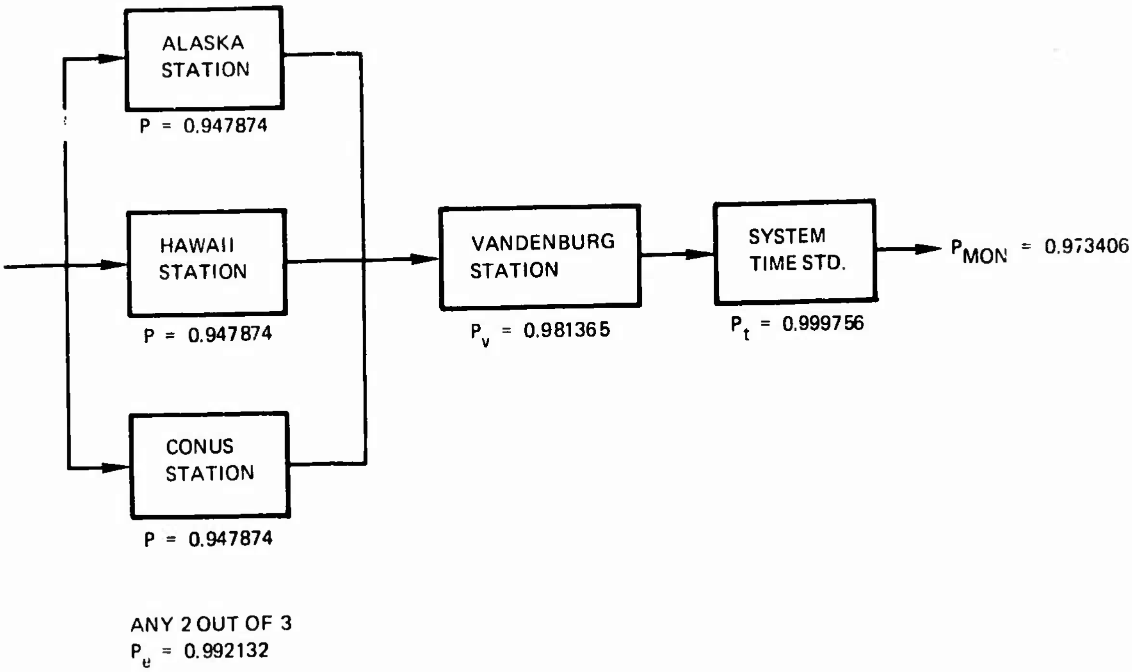


Figure 6-1 Monitor Station Reliability Diagram

diagram which pictorially displays the requirements for mission success.

The monitoring function of one station is defined to be successful if that station, at the time of MCS polling, can deliver at its modem output all the associated downlink L-band data, plus is capable of receiving MCS commands and delivering status. To avoid unnecessary complication of computations, the time-line of 15.25 hours is utilized as the time-line for all four stations.

A unique factor impacts the monitor station computations. The maintenance concept assumes they are unmanned and upon the occurrence of an outage a repairman will be dispatched from the MCS (located at Vandenberg). Hence, the repair time is a function of the stations's location. Worst case travel time is from Vandenberg to Alaska (assumed to be Elmendorf AFB). Current commercial airline schedules show an overall travel time of 31 hours including the necessary land travel. Hence, monitor station MTTR is computed as though the repairman is on-site and then 31 hours worst case travel time is added to this amount (except Vandenberg).

Table 6-13 lists the full complement of elements which comprise one monitor station. All elements must perform. Thus, the overall failure rate is the simple summation of the element failure rates and computes to be 1141.2 (MTBF = 876 hours). Using the MTTR expression given in Paragraph 6.4.2.3, an overall 1.1 hour MTTR results. Adding the 31 hour travel time then gives an actual MTTR of 32.1 hours (except Vandenberg which is 1.1 hours).

Availability of the three outlying stations then calculates to be:

$$A = MTBF/MTBF + MTTR = 876/876 + 32.1 = 0.964662$$

Thus, the probability that an outlying monitor station will perform at the moment a demand is made is 96.47 percent. The probability that the station will continue to operate over the next 15.25 hours that satellites are in view is:

$$R = e^{-\lambda T} = e^{-(0.0011412)(15.25)} = 0.982597$$

The probability that an outlying monitor station will fully perform its function is:

$$P = A \cdot R = (0.964662)(0.982597)$$

$$= 0.947874 \approx 94.79\%$$

This value is shown entered on the reliability diagram (Figure 6-1). The probability that any two out of three of these stations will perform is given by the expression:

$$P_e = 3P^2 - 2P^3 = 3(0.947874)^2 - 2(0.947874)^3 = 0.992132 \approx 99.21\%$$

TABLE 6-13

MONITOR STATION EQUIPMENT AVAILABILITY

EQUIPMENT	λ	MTTR	A
RF INTERFACE PANEL (SIGNAL INPUT)	0.2	1.5	1.0
RF INTERFACE PANEL (TEST SIGNAL)	0.1	1.5	1.0
ALARM PANEL	3.0	1.5	0.999996
4-CHANNEL RECEIVER & PROCESSOR	555.5	1.0	0.999445
BUILT-IN-TEST EQUIPMENT (BITE)	275.0	1.0	0.999725
STATION CPU	70.0	1.0	0.999930
MEMORY 8k–24k	75.0	1.0	0.999925
DISC & DISC CONTROLLER	97.0	2.0	0.999806
DIGITAL I/O & I/O CONTROL	12.0	1.0	0.999988
COMMUNICATION I/O & I/O CONTROL	10.0	1.0	0.999940
COMMUNICATION MODEM	15.0	0.8	0.999988
L-BAND PREAMP & OMNI ANTENNA	16.0	2.0	0.999968
AC POWER CONTROL	0.5	0.5	1.0
BLOWER	5.7	0.5	0.999997
TELETYPEWRITER	OFF-LINE	3.0	

Vandenberg station availability is:

$$A = \frac{MTBF}{MTBF + MTTR} = \frac{876}{876 + 1.1} = 0.998746$$

The probability it will continue to operate over 15.25 hours that satellites are in view is:

$$R = e^{-\lambda T} = e^{-(0.0011412)(15.25)} = 0.982597$$

The probability that Vandenberg will fully perform its function is:

$$P_V = A \cdot R = (0.998746)(0.982597) = 0.981365 \approx 98.14\%$$

The computations, to this point, have calculated the probability of the four monitoring stations performing their portion of the monitoring function. However, one more element is involved. The system time standard (physically located at the MCS) furnishes "perfect time" to the Vandenberg monitor and is a necessary item to complete the monitor function.

Figure 6-2 is a reliability diagram of the redundant time standard. Reliability values for the basic elements are listed in Table 6-14 . As shown by computations in Figure 6-2 , the time system probability is $P_t = 0.999756$.

The final result for the monitoring function is obtained by multiplying:

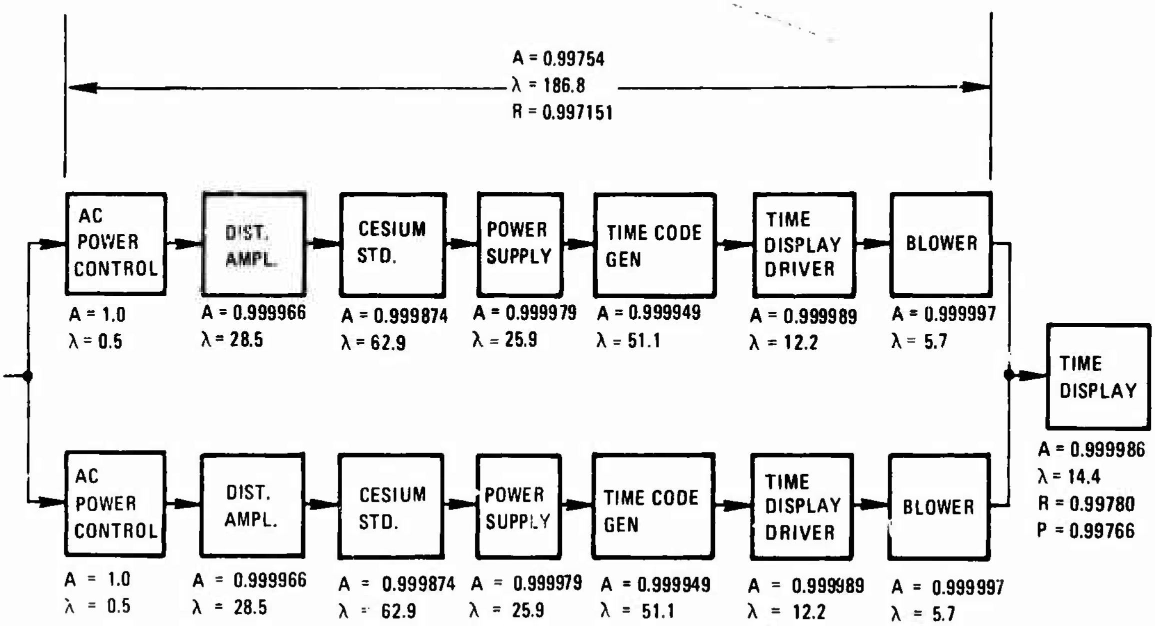
$$P_{MON} = P_e \cdot P_V \cdot P_t = (0.992132)(0.981365)(0.999756) = 0.973406 \approx 97.34\%$$

6.4.4 Analysis of the Upload Station Function

The Upload Station is a combination of monitor and upload hardware collocated with the MCS at Vandenberg. To successfully perform the upload function certain portions of the MCS computer are required and certain portions of the Upload Station are required. Time-lines show the MCS computer equipment is required for 16 minutes (about 0.3 hour) and the upload equipment is required for 50 minutes (about 1 hour).

Table 6-14 lists all the elements necessary to mechnaize the MCS computer along with their associated failure rates and availabilities. Following is a listing of the complement of computer elements necessary to perform the upload function.

Element	λ	A
Console	500.0	0.999301
Disc Drive	350.3	0.999300
Disc Controller	431.0	0.999483
CPU	618.4	0.999073
Memory	1301.9	0.998700
I/O Bus and		



MULTIPLYING THE AVAILABILITIES OF THE UPPER LEG ELEMENTS GIVES $A = 0.999754$

ADDING THE FAILURE RATES OF THE UPPER LEG ELEMENTS GIVES $\lambda = 186.8$

DURATION OF THE MONITOR FUNCTION IS 15.25 HOURS AND $R = \epsilon^{-(0.0001868)(15.25)} = 0.997151$

THE PROBABILITY THAT THE UPPER LEG WILL BE SUCCESSFUL IS $P = A \cdot R$

$$= (0.999754)(0.997151)$$
$$= 0.996906$$

FOR TWO LEGS IN PARALLEL, PROBABILITY $P_p = 2P - P^2 = 2(0.996906) - (0.996906)^2$

$$= 0.999990$$

MULTIPLYING P_p BY THE TIME DISPLAY PROBABILITY GIVES THE OVERALL TIME SYSTEM, $P_t = (0.999990)(0.995766) = 0.999756$

Figure 6-2 MCS Time Standard Reliability Diagram

TABLE 6-14

RELIABILITY TABULATION OF MCS EQUIPMENT

EQUIPMENT	λ	MTTR	A
COMPUTER CONSOLE	500.0	1.4	0.999301
DISC DRIVE	350.3	2.0	0.999300
DISC CONTROLLER	431.0	1.2	0.999483
TAPE TRANSPORT	298.1	1.8	0.999464
TAPE CONTROLLER	372.5	1.8	0.999330
CPU	618.4	1.5	0.999073
MEMORY 65 k	1301.9	2.0	0.997403
I/O BUS & CONTROLLER	130.3	1.0	0.999870
CRT/KEYBOARD	475.0	1.6	0.999241
PRINTER	2519.7	2.0	0.994986
MODEM	15.0	0.8	0.999988
COMMUNICATION CONTROLLER	50.0	1.0	0.999950
CESIUM STANDARD	62.9	2.0	0.999874
TIME CODE GENERATOR	51.1	1.0	0.999949
TIME DISPLAY DRIVER	12.2	0.9	0.999989
TIME DISPLAY	14.4	1.0	0.999986
POWER SUPPLY WITH STANDBY POWER	25.9	0.8	0.999979
DISTRIBUTION AMPLIFIER	28.5	1.2	0.999966
AC POWER CONTROL	0.5	0.5	110
BLOWER	5.7	0.5	0.999997
CARD READER-PUNCH	OFF-LINE	2.6	
VLF COMPARATOR	OFF-LINE	0.8	
OSCILLOSCOPE	OFF-LINE		

Controller	130.3	0.999870
1 of 3 CRT/ Keyboards	negl	1.0
One Modem	15.0	0.999988
Comm Controller	50.0	0.999950
OVERALL	3396.9	0.995672

So the overall computer failure rate is 3396.6 (MTBF = 294 hours), and the availability, A, is 0.995672.

Probability of the computer hardware operating without fault for 0.3 hour is:

$$P = e^{-\lambda T} = e^{-(0.0033969)(0.3)} = 0.998981$$

and the probability of the computer hardware successfully completing its upload function is:

$$P_c = A \cdot P = (0.995672)(0.998981) = 0.994657$$

Table 6-15 lists all the types of elements utilized in the combination monitor and upload station at Vandenberg. Following is a listing of the complement of upload station elements necessary to perform the upload function.

Element	λ	A
Boresight Control Panel	25.0	0.999963
S-Band Loop Check Receiver	50.0	0.999940
Cmd. Interface Test Unit	2.0	0.999997
Power Supply (2 units)	30.0	0.999976
Encoder Interface	7.0	0.999994
Antenna Select Relays	0.5	0.999999
Exciter/Modulator	40.0	0.999936
Transmitter Driver	92.0	0.999834
1 kW Transmitter	246.7	0.999507
S-Band Antenna & Slave Bus	240.0	0.999520
Digital Comparator	10.0	0.999990
Synchro-to-Digital Conv	20.0	0.999984
Servo Control	18.0	0.999977
DC Amplifier	24.0	0.999971
Signal Strength Calib	90.0	0.999856
Disc & Disc Controller	97.0	0.999806
Memory	99.1	0.999901
CPU	70.0	0.999895
Digital I/O & Control	12.0	0.999988
Comm I/O & Control	10.0	0.999990
Comm Modem	15.0	0.999988
CRT/Keyboard	475.0	0.999241
AC Power Control (2 units)	1.0	1.0
Blower (2 units)	11.4	0.999994

TABLE 6-15

RELIABILITY TABULATION OF UPLOAD STATION EQUIPMENT

EQUIPMENT	λ	MTTR	A
BORESIGHT CONTROL PANEL	25.0	1.5	0.999963
S-BAND LOOP CHECK RECEIVER	50.0	1.2	0.999940
COMMAND INTERFACE TEST UNIT	2.0	1.4	0.999997
POWER SUPPLY	15.0	0.8	0.999988
ENCODER INTERFACE	7.0	0.9	0.999994
ANTENNA SELECT RELAYS	0.5	1.2	0.999999
EXCITER/MODULATOR	40.0	1.6	0.999936
TRANSMITTER DRIVER	92.0	1.8	0.999834
1 kW TRANSMITTER	246.7	2.0	0.999507
S-BAND ANTENNA & SLAVE BUS	240.0	2.0	0.999520
DIGITAL COMPARATOR	10.0	1.0	0.999990
SYNCHRO-TO-DIGITAL CONVERTER	20.0	0.8	0.999984
SERVO CONTROL	18.0	1.3	0.999977
DC AMPLIFIER	24.0	1.2	0.999971
RF INTERFACE PANEL	0.2	1.5	1.0
4-CHANNEL RECEIVER & PROCESSOR	555.5	1.0	0.999445
ALARM PANEL	3.0	1.5	0.999996
BUILT-IN-TEST EQUIPMENT (BITE)	275.0	1.0	0.999725
SIGNAL STRENGTH CALIBRATOR	90.0	1.6	0.999856
DISC & DISC CONTROLLER	97.0	2.0	0.999806
MEMORY 16 k	99.1	1.0	0.999901
CPU	70.0	1.5	0.999895
DIGITAL I/O & I/O CONTROL	12.0	1.0	0.999988
COMMUNICATION I/O & I/O CONTROL	10.0	1.0	0.999990
COMMUNICATION MODEM	15.0	0.8	0.999988
L-BAND PREAMP & OMNI ANTENNA	16.0	2.0	0.999968
CRT/KEYBOARD	475.0	1.6	0.999241
AC POWER CONTROL	0.5	0.5	1.0
BLOWER	5.7	0.5	0.999997
OSCILLOSCOPE	OFF-LINE		
SPECTRUM ANALYZER	OFF-LINE		
INTRASTATION COMMUNICATION PANEL	OFF-LINE		
L-BAND PREAMP & LOG-PERIODIC ANTENNA	OFF-LINE		

OVERALL	1685.7	0.997247

The upload hardware failure rates total to 1685.7 (MTBF = 593 hours) and the availabilities multiply out to A = 0.997247.

Probability of the upload hardware operating without fault for 1 hour is:

$$P = e^{-\lambda T} = e^{-(0.0016857)(1)} = 0.998314$$

and the probability of the upload hardware successfully completing its upload function is:

$$P_u = A \cdot P = (0.997247)(0.998314)$$

$$= 0.995566$$

Combining the computer results with the upload station results gives the overall probability of successful uploading:

$$P_{ULS} = P_c \cdot P_u = (0.994657)(0.995566) = 0.990247 \quad 99.02\%$$

6.4.5 Analysis of the MCS Function

The time the computer has to function to transfer upload data to the Upload Station was included as a part of the upload function analysis. The remaining necessary computer time is included in this analysis.

The remaining computer time consists of the sum of the monitor station polling times, status monitoring, scheduling, the processing of navigation/clock data, and the generating of upload messages. This time totals to about five hours per day.

Table 6-14 lists the elements which are necessary to comprise the MCS computer along with their associated reliability values. The complement of elements necessary to mechanize the computer for the MCS function are tabulated below.

Element	λ	A
Console	500.0	0.999301
Disc Drive	350.3	0.999300
Disc Controller	431.0	0.999483
1 of 2 Tape Transports	negl	1.0
Tape Controller	372.5	0.999330
CPU	618.4	0.999073
Memory	1301.9	0.997403
I/O Bus & Controller	130.3	0.999870
1 of 3 CRT/Keyboard	negl	1.0
Printer	2519.7	0.994986

Four Modems	60.0	0.999952
Comm I/O & Controller	50.0	0.999950
OVERALL	6334.1	0.988695

The computer hardware failure rates total to 6334.1 (MTBF = 158 hours) and the availabilities multiply out to A = 0.988695.

Probability of the computer hardware operating without fault for 5 hours is:

$$P = e^{-\lambda T} = e^{-(0.0063341)(5)} = 0.968330$$

and the probability of the computer hardware successfuly completing its functions is:

$$P_{MCS} = A \cdot P = (0.988695)(0.968330) = 0.957383 \approx 95.74\%$$

6.4.6 Control Segment Probability of Success

Collecting the probabilities of success for the four configuration items functional areas and taking their product gives the final result for the Phase I Control Segment. This probability computes to be:

$$P_{CS} = P_{MON} \cdot P_{ULS} \cdot P_{MCS} \cdot P_{TCN} = (0.973406)(0.990247)(0.957383)(0.938)$$
$$= 0.865618 \approx 86.56\%$$

The forecast of an 86 percent probability of successfully uploading satellites well exceeds the Phase I 70% requirement. The Phase I forecast also provides some insight into configuration alterations that may be required to attain the Phase III requirement of a 99% probability of success. For example, MCS computer redundancy is indicated and improvements will have to be realized in the monitor and upload areas. The fact the Phase I configuration success probability approaches that required for Phase III is a gratifying revelation.

6.4.7 Preliminary Maintenance Concept.

6.4.7.1 Purpose and Scope. This paragraph identifies and defines the Maintenance Concept for the Phase I Control Segment (Master Control Station, Monitor Stations and Upload Station).

6.4.7.2 Operational Requirements.

Master Control Station - will operate six hours per day except for corrective maintenance as required. Preventive maintenance shall be scheduled during the 18 hour non-operating period.

Monitor Stations - will operate 16 hours per day except for corrective maintenance as required. Preventive maintenance shall be scheduled during non-operating hours.

Upload Station - will operate one hour per day except for corrective maintenance as required. Preventive maintenance shall be scheduled during non-operating hours.

6.4.7.3 Fault Detection. Fault detection and fault localization of the monitor stations will be performed automatically by built in test equipment (BITE). BITE will localize faults to one of the following items of equipment:

a. Antenna/preamp package

b. IF/Digital Station Processor (one of four)

c. Monitor Station Processor

d. Communications Modem

e. Built-In-Test-Equipment (BITE)

When a fault occurs at a Monitor Station, BITE will localize and identify the fault to one of the above assemblies. The BITE data will be interrogated periodically by the Master Control Station computer status program. Monitor Station status will be displayed at the Master Control Station.

Fault Detection and localization for the Master Control Station will be performed by computer initiated, operational and fault localization test at the MCS. Fault localization will be to the assembly level. Operations and maintenance personnel will isolate faults below the assembly level, remove and replace the faulty subassembly or peice part, and restore the equipment to operational status.

The Upload Station will be checked out with BITE. The BITE will be capable of performing loop checks and verifying operation of the Upload Station Equipment Faulty equipment will be detected and localized to the assembly level via the loop checks. Operations and maintenance personnel will isolate faults below the assembly level, remove and replace the faulty subassembly or peice part, and restore the equipment to operational status.

6.4.7.4 Equipment Restoration. Restoration of equipment at the Remote Monitor Station will be performed by removing and replacing assemblies identified as faulty via the BITE and computer monitoring of the station.

Restoration of equipment at the Master Control Station and Upload Station will be performed by isolating to the subassembly or piece part; the subassembly or piece part will be removed and replaced for equipment restoration.

6.4.7.5 Levels of Maintenance. There shall be three levels of maintenance required to maintain the GPS in operational condition,

Organizational, Intermediate and Depot. Maintenance to be performed at these levels will be in accordance with the following guidelines.

6.4.7.5.1 Organizational Maintenance. Organizational maintenance personnel will be primarily concerned with the Master Control Station and Upload Station. They will perform 1) Corrective maintenance actions which restore equipment to operational status, and 2) Preventive maintenance actions which minimize the need for corrective maintenance. They will:

- Isolate failures in on-line equipment to the hardwired assembly, subassembly, or piece part level; and replace the item if it has been designated as an LRU.
- Perform preventive maintenance as scheduled
- Adjust and align on-line equipment in conjunction with performance and operations checks
- Assist Intermediate maintenance personnel as necessary

6.4.7.5.2 Intermediate Maintenance. Intermediate maintenance personnel will be the principal repair group for the GPS. They will be concerned with:

a. Off-line repair of faulty GPS assemblies and subassemblies

b. Restoring Monitor Stations by removing and replacing assemblies

c. Preventive maintenance for the Monitor Stations

In general Intermediate maintenance personnel will:

- Restore Monitor Stations to operational status by removing and replacing assemblies that have been identifed as faulty by the Master Control Station Monitor.
- Repair failed items of equipment (assemblies, subassemblies, and other designated LRU's) off-line, restore them to operational capability, and return them to operational maintenance.
- Align and adjust items of operation equipment which are beyond the capability of organizational maintenance
- Perform preventive maintenance tasks for the Monitor Stations as scheduled.
- Assist Organizational Maintenance as required.
- Ensure that test equipment is calibrated as scheduled by the Precision Measurement Equipment Laboratory (PMEL).

- Provide support to Depot Maintenance on-site maintenance as required.

6.4.7.5.3 Depot Maintenance. Depot Maintenance will normally be performed off-site at a designated government facility or for specific equipment at a contractors plant. Depot Maintenance personnel will:

- Perform corrective maintenance on-site on the Upload Station Antennas which is beyond the capability of Intermediate Maintenance.

- Assist Intermediate Maintenance as necessary where speical test, calibration, or maintenance equipment is required for corrective maintenance.

- Perform Depot Maintenance fo testing, servicing, calibration and alignment of station equipment beyond the capability of Intermediate Maintenance. This effort will normally be on a periodic scheduled basis but may be required on an emergency basis.

6.4.7.6 Precision Measurement Equipment. Maintenance of Precision Measurement Equipment for GPS will be performed by a certified mobile calibration tieam. Equipment which cannot be calibrated and certified by such a team will be evacuated to a designated PMEL depot for required maintenance.

6.4.7.7 Logistics. Logistics will provide the established station allowances of spares, tools, and test equipment. They will also be responsible for resupply, shipping, receiving, transportation, storage, and inventory control.

APPENDIX A

A THUMBNAIL DESCRIPTION OF THE GPS NAVIGATION PROCEDURE

(Paraphrased from "Satellite System for Integrated Communications, Navigation, and Identification" by P. M. Diamond, The Aerospace Corporation, El Segundo, California.)

APPENDIX A

A THUMBNAIL DESCRIPTION OF THE GPS NAVIGATION PROCEDURE

A variety of navigation systems using satellites can be configured. Analysis indicates that only systems based on measuring the ranges between satellites and the user, or the range difference between links to pairs of satellites, can meet the goal of high accuracy while being available to users in high speed aircraft. Furthermore, the desire to accommodate high speed users requires all of the measurements needed to establish a navigation fix to be made simultaneously.

Measurement of range can be accomplished by comparing the time of arrival of a signal with a clock at the user synchronized to a clock at the satellite. To maintain clock synchronization with any clock presently feasible for inclusion in the user's equipment, one additional measurement must be made. Since a three-dimensional fix is required, signals from four satellites need to be received. By measuring the time of arrival of the four signals relative to the user's clock, three position coordinates and a clock correction can thus be determined. If, in addition, the frequency shift is measured, the three-component velocity vector of the user can be found. Since a clock correction is calculated, the user effectively has an extremely accurate time standard, and frequency standard, available to him.

A system using the measurement technique just described will be termed a one-way pseudorange and pseudorange rate system. Such a system makes measurements made by the range and range rate measurements made by the use of a synchronized user clock. It is also equivalent to (except for the computation algorithm) a hyperbolic system in which three range differences are measured to four satellites.

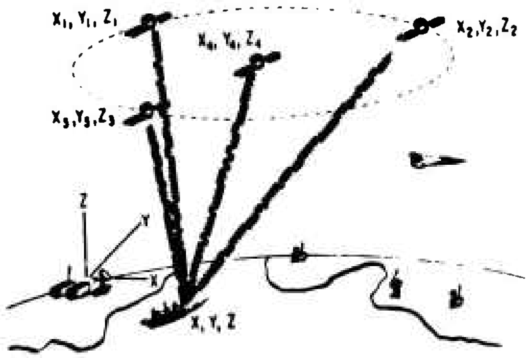
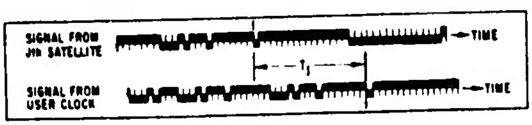


FIGURE A-1 Pseudoranging to Four Satellites



- PSEUDO-RANGE $= T_j \cdot C = \sqrt{(X-X_j)^2 + (Y-Y_j)^2 + (Z-Z_j)^2} - T_B \cdot C$

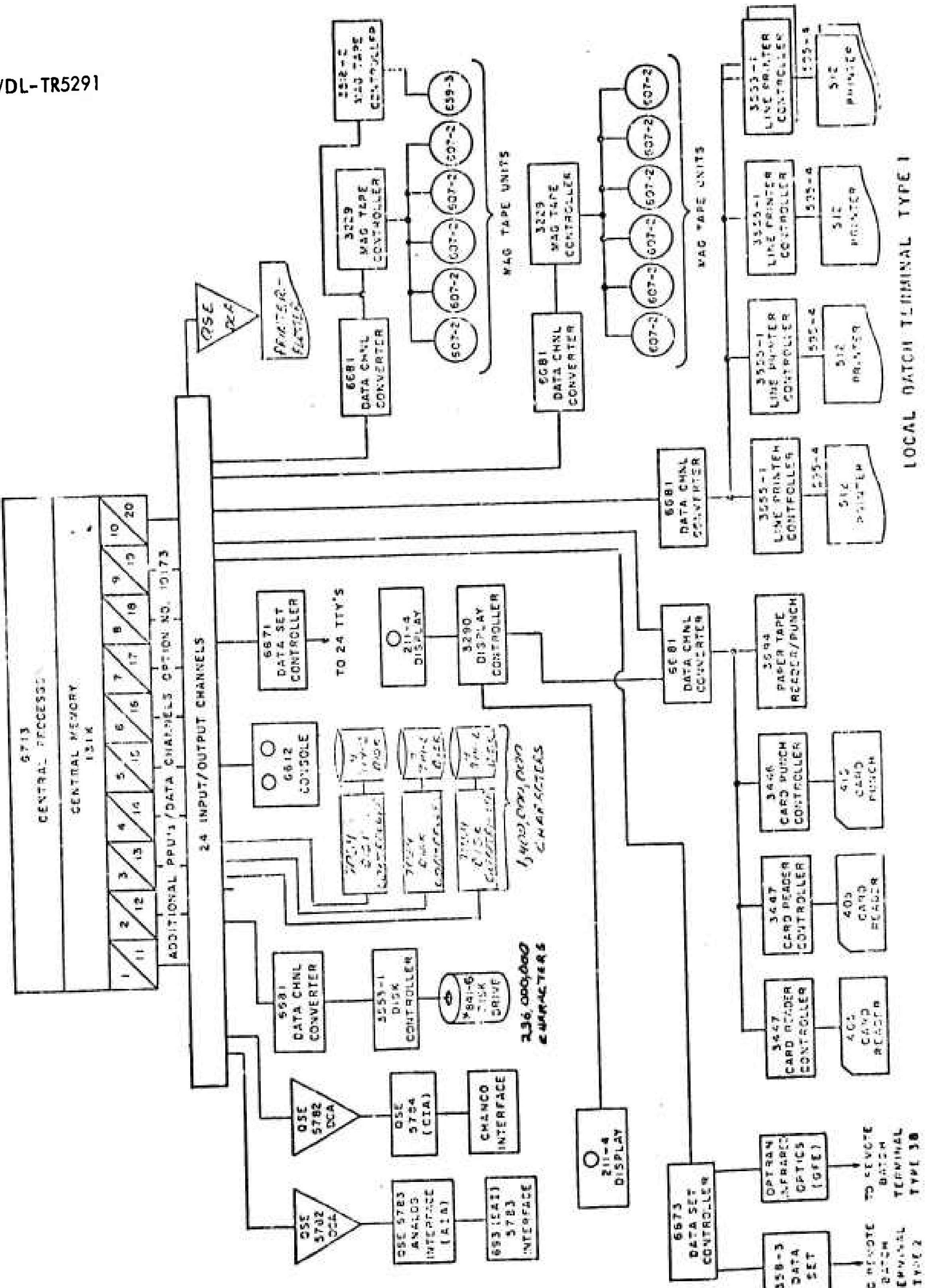
- PSEUDO-RANGE RATE $= \dot{T}_j \cdot C = \dfrac{(X-X_j)(\dot{X}-\dot{X}_j)+(Y-Y_j)(\dot{Y}-\dot{Y}_j)+(Z-Z_j)(\dot{Z}-\dot{Z}_j)}{\sqrt{(X-X_j)^2+(Y-Y_j)^2+(Z-Z_j)^2}} - \dot{T}_B C$

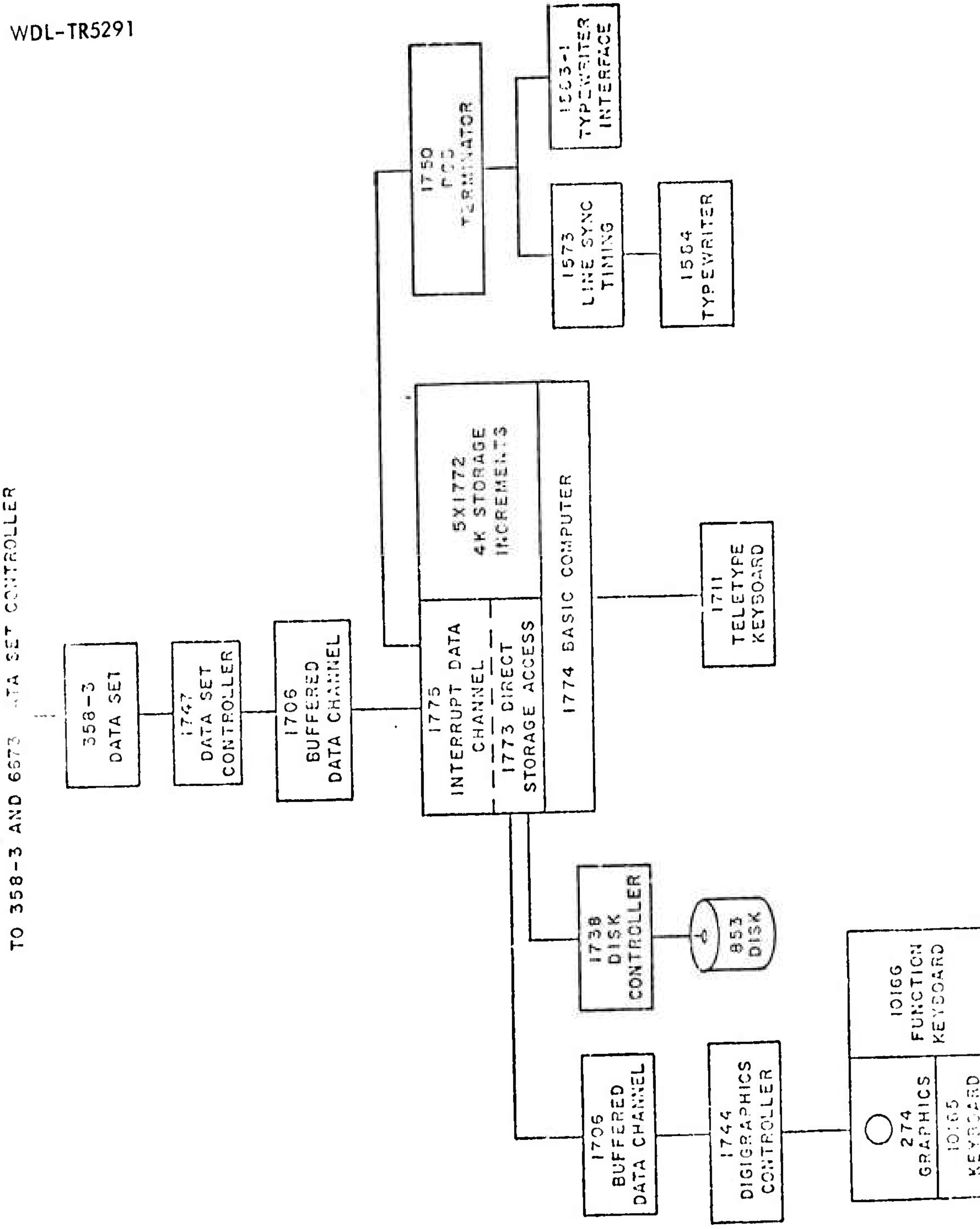
- SINCE $X_j, Y_j, Z_j, \dot{X}_j, \dot{Y}_j, \dot{Z}_j$, ARE KNOWN, 4 T_j's AND 4 $\dot{T}_j$'s ALLOW SOLUTION FOR USER POSITION (X,Y,Z), AND VELOCITY $(\dot{X},\dot{Y},\dot{Z})$, AND TIME BIAS (T_B)

FIGURE A-2 Determination of User Position, Velocity and Time

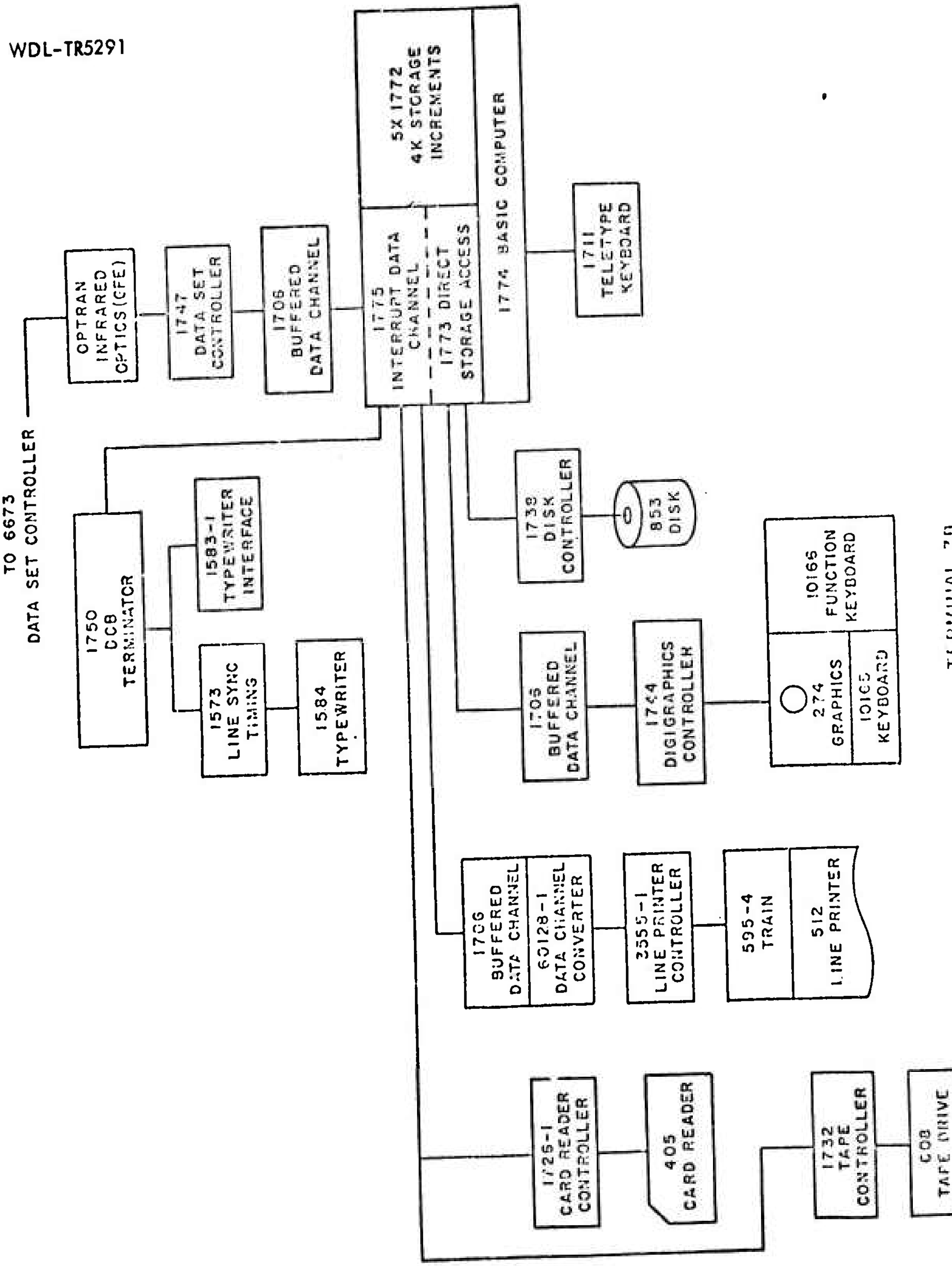
APPENDIX B

NWL DATA PROCESSING EQUIPMENT CONFIGURATION


6713 CENTRAL PROCESSOR
CENTRAL MEMORY 131K
ADDITIONAL PPU's / DATA CHANNELS OPTION NO. 10173
24 INPUT/OUTPUT CHANNELS
6671 DATA SET CONTROLLER
TO 24 TTY's
6612 CONSOLE
211-4 DISPLAY
3290 DISPLAY CONTROLLER
6681 DATA CHNL CONVERTER
3553-1 DISK CONTROLLER
841-6 DISK DRIVE
236,000,000 CHARACTERS
QSE 5782 DCA
QSE 5784 (CIA)
CHANCO INTERFACE
QSE 5783 ANALOG INTERFACE (AIA)
3229 MAG TAPE CONTROLLER
607-2
MAG TAPE UNITS
3555-1 LINE PRINTER CONTROLLER
512 PRINTER
3694 PAPER TAPE READER/PUNCH
3446 CARD PUNCH CONTROLLER
415 CARD PUNCH
3447 CARD READER CONTROLLER
405 CARD READER
6673 DATA SET CONTROLLER
358-3 DATA SET
TO REMOTE BATCH TERMINAL TYPE 2
TO REMOTE BATCH TERMINAL TYPE 3B
LOCAL BATCH TERMINAL TYPE I



BUILDING 1200 TERMINAL


TO 6673
DATA SET CONTROLLER
OPTRAN INFRARED OPTICS (CFE)
1747 DATA SET CONTROLLER
1706 BUFFERED DATA CHANNEL
1775 INTERRUPT DATA CHANNEL
1773 DIRECT STORAGE ACCESS
5X 1772 4K STORAGE INCREMENTS
1774 BASIC COMPUTER
1711 TELETYPE KEYBOARD
1750 DCB TERMINATOR
1583-1 TYPEWRITER INTERFACE
1573 LINE SYNC TIMING
1584 TYPEWRITER
1738 DISK CONTROLLER
853 DISK
1706 BUFFERED DATA CHANNEL
1744 DIGIGRAPHICS CONTROLLER
274 GRAPHICS
10166 FUNCTION KEYBOARD
10165 KEYBOARD
1706 BUFFERED DATA CHANNEL
60128-1 DATA CHANNEL CONVERTER
3555-1 LINE PRINTER CONTROLLER
595-4 TRAIN
512 LINE PRINTER
1725-1 CARD READER CONTROLLER
405 CARD READER
1732 TAPE CONTROLLER
608 TAPE DRIVE

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13. ABSTRACT

This report provides description of control segment, satellite ephemeris generator requirement, timing required, monitor station location and general constraints.

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14. KEY WORDS	LINK A		LINK B		LINK C	
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Satellite Ephemeris						
Upload Stations						
Master Control Station						
Monitor Station						

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